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DEPARTMENT OF ENVIRONMENTAL SCIENCES  
UNIVERSITY OF VIRGINIA

**CAPE HATTERAS  
NOURISHMENT STUDY  
1974-1975**

NATIONAL PARK SERVICE  
SOUTHEAST REGIONAL OFFICE  
GRANT NO. CX 500040462



Cape Hatteras Beach Nourishment Study  
Post-Pumping Report  
March 1974 - February 1975

by

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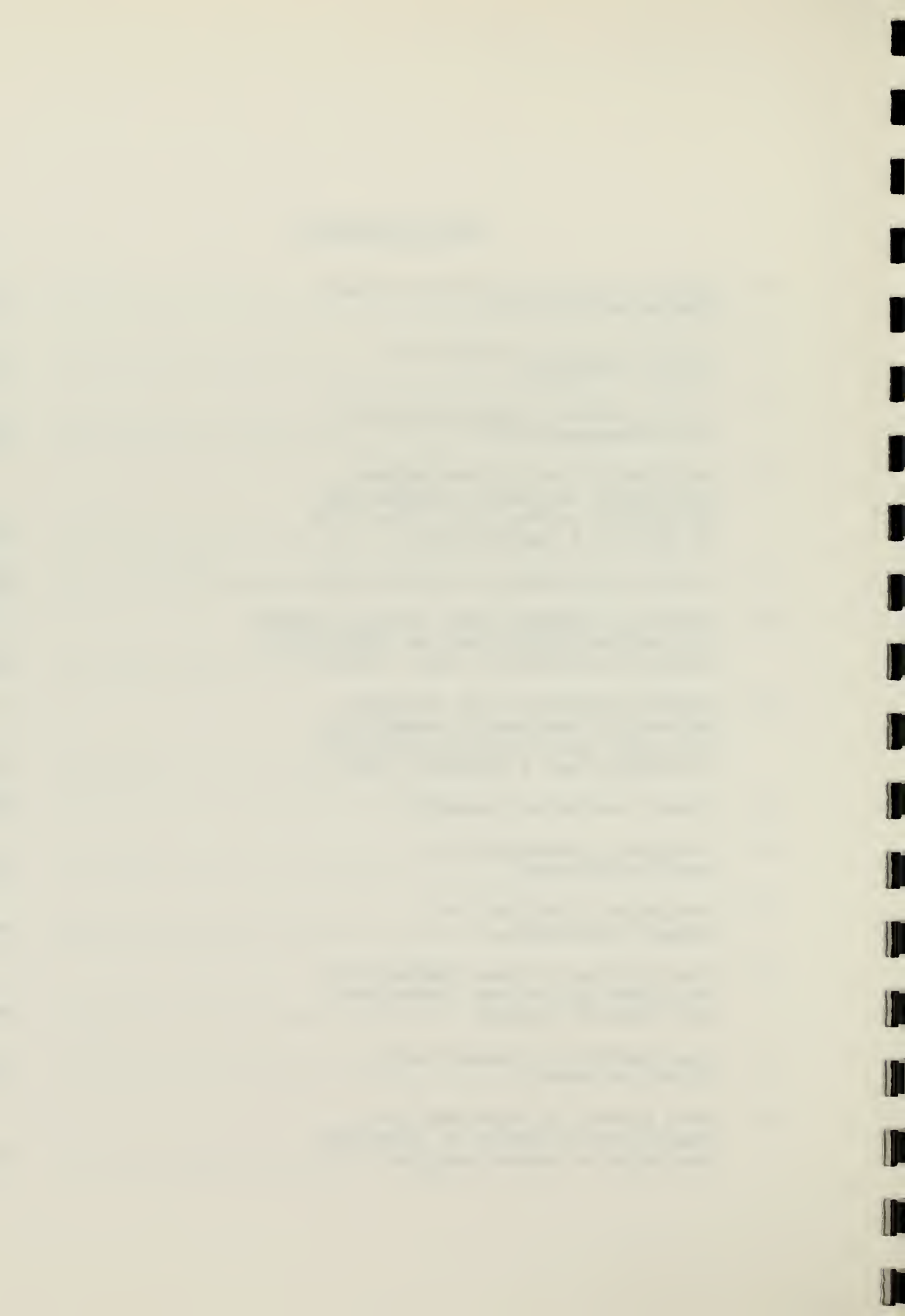
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## I. INTRODUCTION

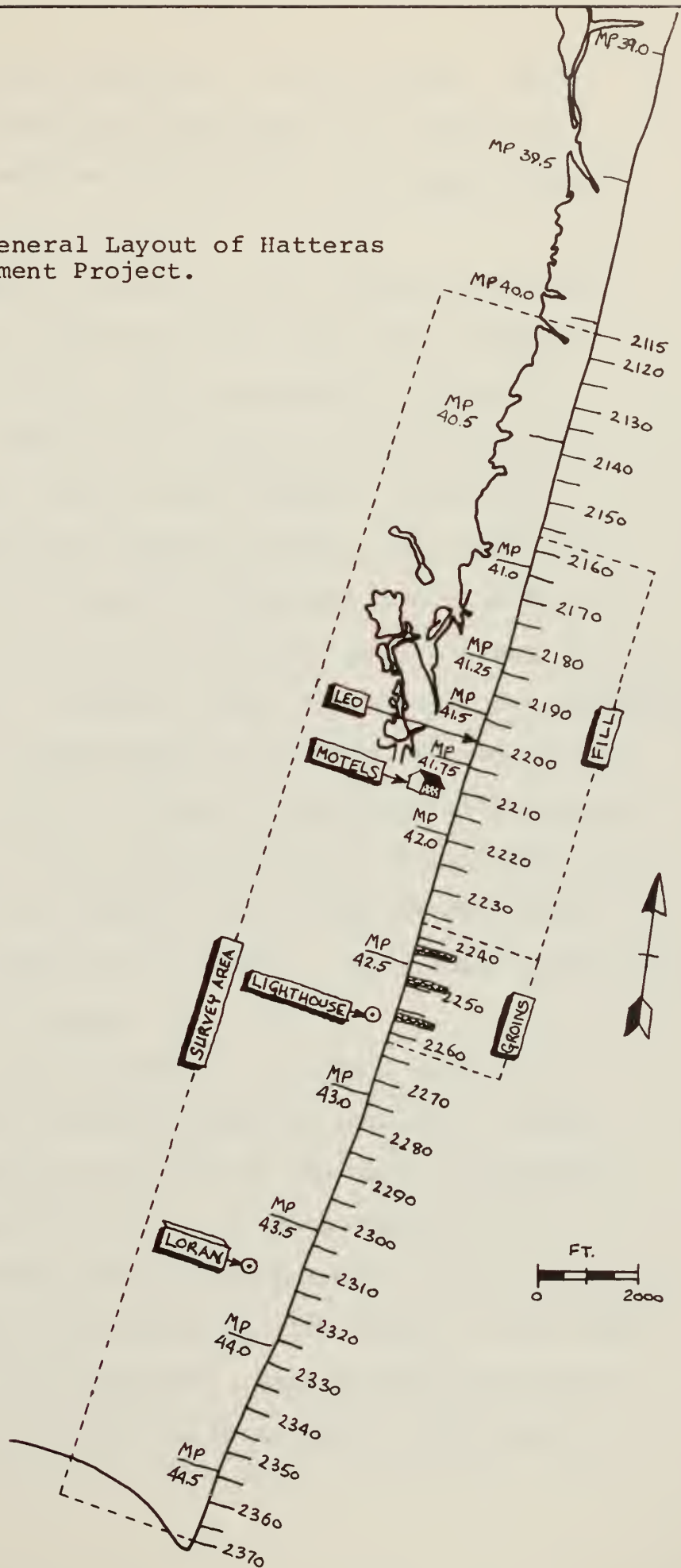
The beach at Cape Hatteras, North Carolina is exposed to one of the most severe wave climates along the eastern North Atlantic coast. Periodically, in an effort to check the pace of shoreline recession, various engineering projects have been initiated to protect the remaining beach. The latest such project was the placement of 1.25 million cubic yards of fill along approximately 1.5 miles of shoreline at Buxton in 1973.

Figure 1.1 shows the general layout for the beach nourishment project. The fill material was excavated from Cape Point and pumped to the fill area, roughly between Mile Posts 42.5 and 41.0. By dredging fill material from Cape Point, it was possible to obtain nourishment sand whose texture closely matched that of the beach in the fill area. This similarity was an important factor in achieving high levels of retention for the fill. The final size of the borrow pit was approximately 2500 feet by 1000 feet with an average depth of 15 feet. At the time of final pumping, there was no connection with the ocean. Subsequently, an inlet cut into the southwest side and has remained open to date.

In the fill area, the 1.25 million cubic yards of fill resulted in an increase in subaerial beach width of



Figure 1.1, General Layout of Hatteras Beach Nourishment Project.

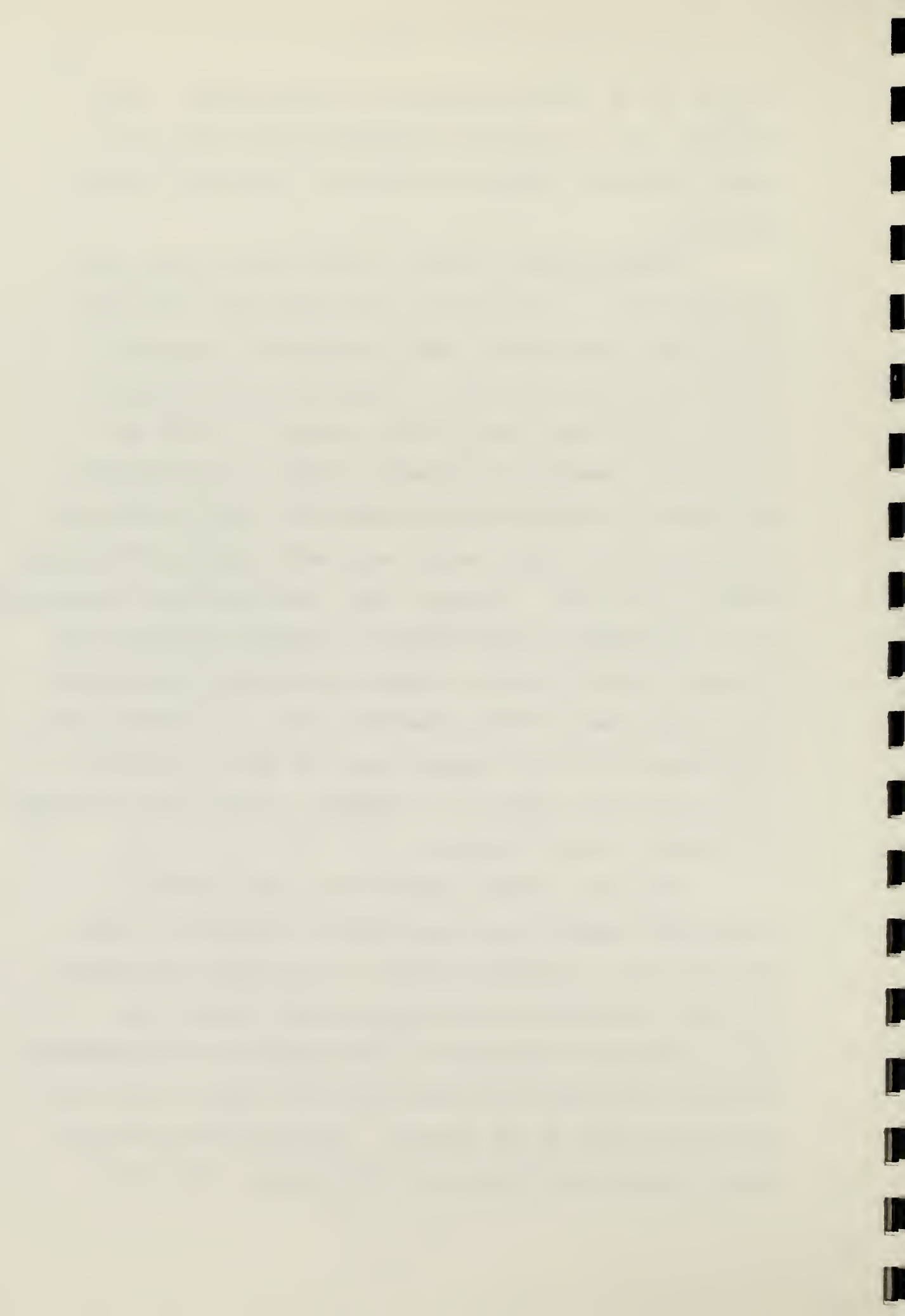




roughly 200 to 300 feet along the 1.5 mile beach. This material, as it is moved and reworked by the waves and storms, provides temporary protection to the Cape Hatteras shoreline.

Pumping began in March of 1973 and continued into September 1973. In conjunction with this fill operation, The National Park Service (NPS) contracted a scientific study of the fill material, its physical and ecological impact on the beach, and the wave climate. During the pumping and immediate post-pumping stages, this study was undertaken by Coastal Research Associates (CRA), under the direction of Dr. Robert Dolan, and their analysis was reported monthly to the NPS. In March, 1974, this study was transferred to the Department of Environmental Sciences, University of Virginia, with Dr. John S. Fisher as principal investigator. This second phase of the scientific study has continued the monitoring of the fill material and its impact during the first year after completion of pumping. This report describes that effort and its findings.

From the initial stages of this fill project, a significant emphasis has been placed on obtaining a sound data base for a thorough analysis of the beach nourishment. Although the responsibility for the data changed from Coastal Research Associates to the Department of Environmental Sciences, continuity was maintained with regard to the field program and much of the analysis. Some modifications were made, and these are detailed in this report. This data,



extending from pre-fill periods to the present, is an important contribution to the development of long-term plans for this coastal area. Continued monitoring in future years will further add to this development.

In order to insure a complete evaluation of the post-pumping behavior of the fill, a wide spectrum of observations and field measurements were undertaken.

A general survey of the subaerial beach extending both north and south of the fill area was made bi-weekly. A mid-tide sediment sample was collected at each station. These profiles were 500 feet apart and extended from the low-water level to a baseline far up the backshore. A second set of subaerial beach measurements were also made bi-weekly. This set consisted of a simple determination of the beach width every 1/2 mile from Cape Point to Mile Post 39, also with a mid-tide sand sample. This second set of data is a continuation of an earlier study initiated by Dr. Robert Dolan.

In order to quantify the subaqueous beach changes, a program of fathometer soundings was carried out along the entire survey area. Sand samples were taken at select positions along these profiles. The difficulty in obtaining this data resulted in a more interrupted schedule than that of the subaerial profiles, however, approximately six monthly data sets were collected.

The borrow pit was surveyed periodically in order to quantify what filling, if any, occurred. Additional surveys



were made at several points along the shore where significant erosion appeared to be happening. These profiles, as well as the subaerial ones described above, were also collected after severe storms.

Observations were made daily of waves, wind, and longshore current as part of a Littoral Environmental Observation Program (LEO) described in detail in Section II. Daily photographs were taken from the top of the lighthouse and daily tide data recorded from the NOAA weather station for the tide gage at Avon, 10 miles north of Cape Point.

The following sections of this report describe the details of this field program and the resulting data analysis. A discussion of the application of vertical aerial photography flown for the NPS by NASA-Wallops is included, as well as an initial attempt to use detailed wave refraction diagrams to predict areas of severe shoreline erosion and overwash, i.e., shoreline vulnerability.



## II. DESCRIPTION OF FIELD STUDIES

### 2.1. Subaerial Beach Profiles

In order to calculate the volume of sand eroded and accreted on the subaerial beach, detailed profiles were surveyed every two weeks. Fifty-two stations were established at 500 feet intervals from Mile Post 40.0 to Cape Point, Figure 1.1. These profiles were taken with an automatic level and survey rod and extended from the project baseline on the backshore into the swash zone. Readings were made at prominent features and breaks in beach slope. This data was later transcribed from the field books to computer cards for both storage and computation. In addition, the CRA data for all post-fill profiles were added to this computer file, as well as the subaerial beach profile immediately before pumping began.

Figure 2.1 illustrates one of these profiles, at station 2200+50. The impact on the beach of the fill material is apparent, as well as the subsequent reworking and erosion of this material during the year. It should be noted that the fill was not shaped by the contractor during pumping but rather left to be shaped by the waves. This accounts for the depression landward of the fill, extending beyond the NPS boundaries.

A second set of bi-weekly measurements were made of the approximate beach width at 15 stations from Mile Post 39



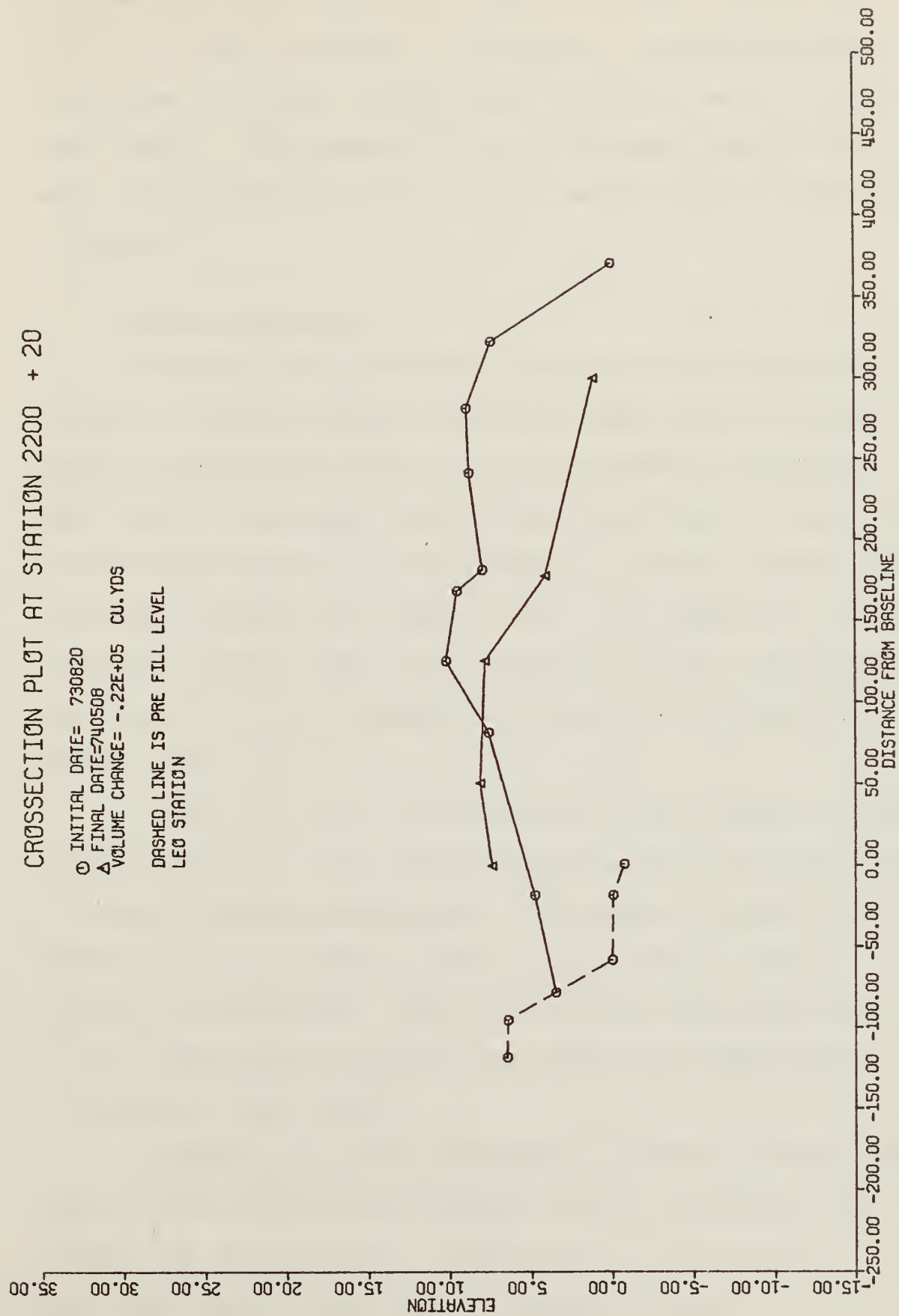


Figure 2.1, Subaerial beach profile at station 2200+20



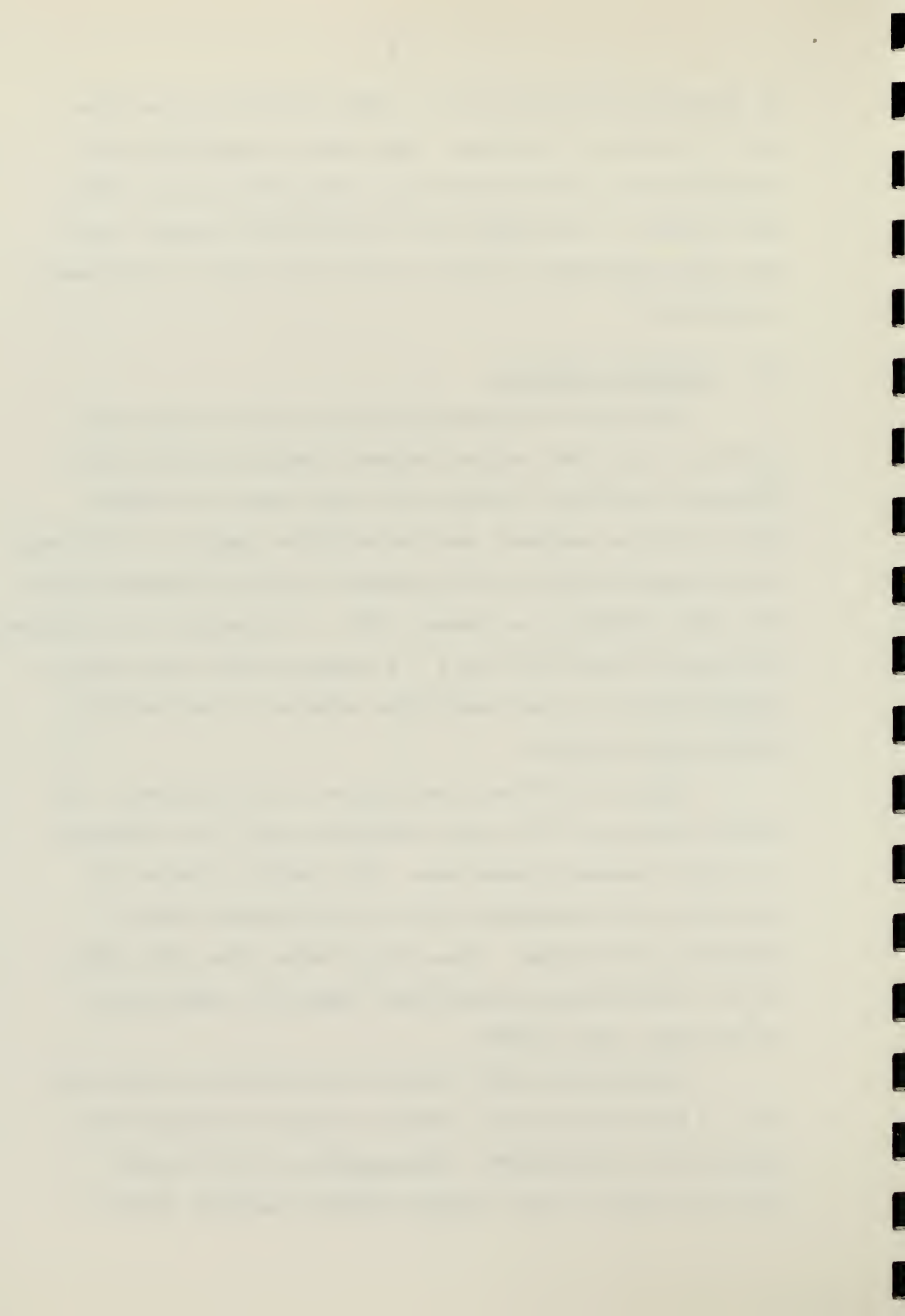
to Cape Point Mile Post 44.5. These stations varied from 1/2 to 1/4 mile in spacing. This data is presented with discussion in a later section and referred to as the "mile post survey." The samples for the ecological impact study were also collected as part of this survey and are discussed in Section V.

## 2.2. Sediment Sampling

For both the subaerial profiles and the mile post surveys, a mid-tide surface sediment sample was collected. Manpower constraints limited the total number of samples which could be analyzed, and the mid-tide sample is considered to be representative of the material in active transport with the waves (Krumbein and James, 1974). The sample was collected by digging through the top 2 - 3 inches by hand, and thus is representative of the cumulative effects of the previous several tidal cycles.

During the first three months of this contract, the texture analysis of the sand continued using the techniques of Coastal Research Associates. This method consists of measuring the intermediate axis of forty grains under a projecting microscope. These forty values have been shown to be a statistically significant sample for computation of the mean, Dolan (1972).

Although the CRA's method was relatively simple and fast, a more conventional sediment analysis technique was desired for this project. Consequently, at the outset, plans were made to use a Rapid Sediment Analyzer (RSA) to



make the texture analysis. The RSA is a useful way to measure sand size because it models the hydraulic environment of the transported sediment, CERC (1973). A RSA unit was available at the Department of Environmental Sciences, although the installation of a new pressure transducer and other repairs delayed its implementation until early June.

In order to be able to relate the size analysis using the microscope to that of the RSA, a number of samples were run with both methods. A fairly linear correlation was found, and for the purposes of this study, it was concluded that the microscoped data could be included with the RSA data without correction.

### 2.3. Bathymetric Profiles

The monitoring of the changes in the sub-aqueous beach was considerably more difficult than the sub-aerial profiling described above. Ideally, one would like to extend a profile from the baseline to the seaward limit of change. For Cape Hatteras, this distance may be as much as several miles offshore. Within the first 300 feet seaward of the mean water level, the bottom goes from an inshore trough, about four to eight feet deep, to an inshore bar one to four feet deep and then generally to an outer trough and bar. The outer bar varies from around 1000 feet to 4000 feet offshore and water depth over this bar is between 8 to 20 feet.

The bathymetric profiles were taken with a Raytheon Fathometer operated from a 40 foot fishing boat, chartered



by the day. This vessel could not cross the inner bar due to the shallow depths and breaking waves. Therefore, the profile generally runs from about 300 feet from mean water level out to about one mile offshore, depending upon bottom slope. Range poles were fixed on the beach at right angles to the baseline. The distance from baseline to the boat was measured with an optical rangefinder. As the boat moved offshore, its speed was determined by timing the travel between marker floats released periodically from the craft.

Due to scheduling problems and poor weather, only five complete surveys were accomplished for the 52 stations used in the sub-aerial beach surveys. Additional profiles were run, either as incomplete sets or at specific areas of interest. All of these data are included in the appendices.

The problem of connecting the subaerial beach profile to the fathometer runs was never adequately resolved. The rather hostile inshore zone does not permit a simple method of profiling. Two sets of data were obtained by having the rod man wade and swim out to the inner bar.

#### 2.4. Daily Observations

A program of daily observations was initiated by CRA at the beginning of this study. Wave height and period, as well as wind speed, direction and other parameters, were all recorded. This information was needed to relate the computed changes in the fill material to the changing wave and wind conditions.



With the start of the present contract, this program of daily observations was expanded and reorganized. A cooperative agreement was entered into with the U. S. Army Coastal Engineering Research Center (CERC) to collect these data as part of their Littoral Environment Observation Program (LEO), Bruno and Hiipakka (1973). The LEO program includes the systematic daily observation of:

- (a) wave period
- (b) breaker height
- (c) wave angle at breaker
- (d) wave type
- (e) wind speed
- (f) wind direction
- (g) foreshore slope
- (h) width of surf zone
- (i) longshore current speed and direction
- (j) rip currents
- (k) description of beach cusps, if any.

These data were sent to CERC for periodic computer processing for statistical analysis. In addition, a copy of the data was retained in Charlottesville as part of the computer data bank for the project. The data were plotted monthly in order to identify the relationship between the storm periods and the retention of the fill material, as discussed in Section IV. Unfortunately, an analysis of the data by CERC was not available for this report. All of the LEO data are included in the appendices.

4. The fourth part of the document discusses the implications of the findings. It suggests that the results have significant implications for the field of study and may lead to further research in this area.

5. The fifth part of the document concludes the study. It summarizes the main findings and provides a final statement on the importance of the research.

In addition to the LEO observations, the daily tide elevations for the Avon tide gage, located 10 miles north of Cape Point, were obtained from the NOAA weather station at Buxton. These data were needed in the analysis of the fathometer profile.

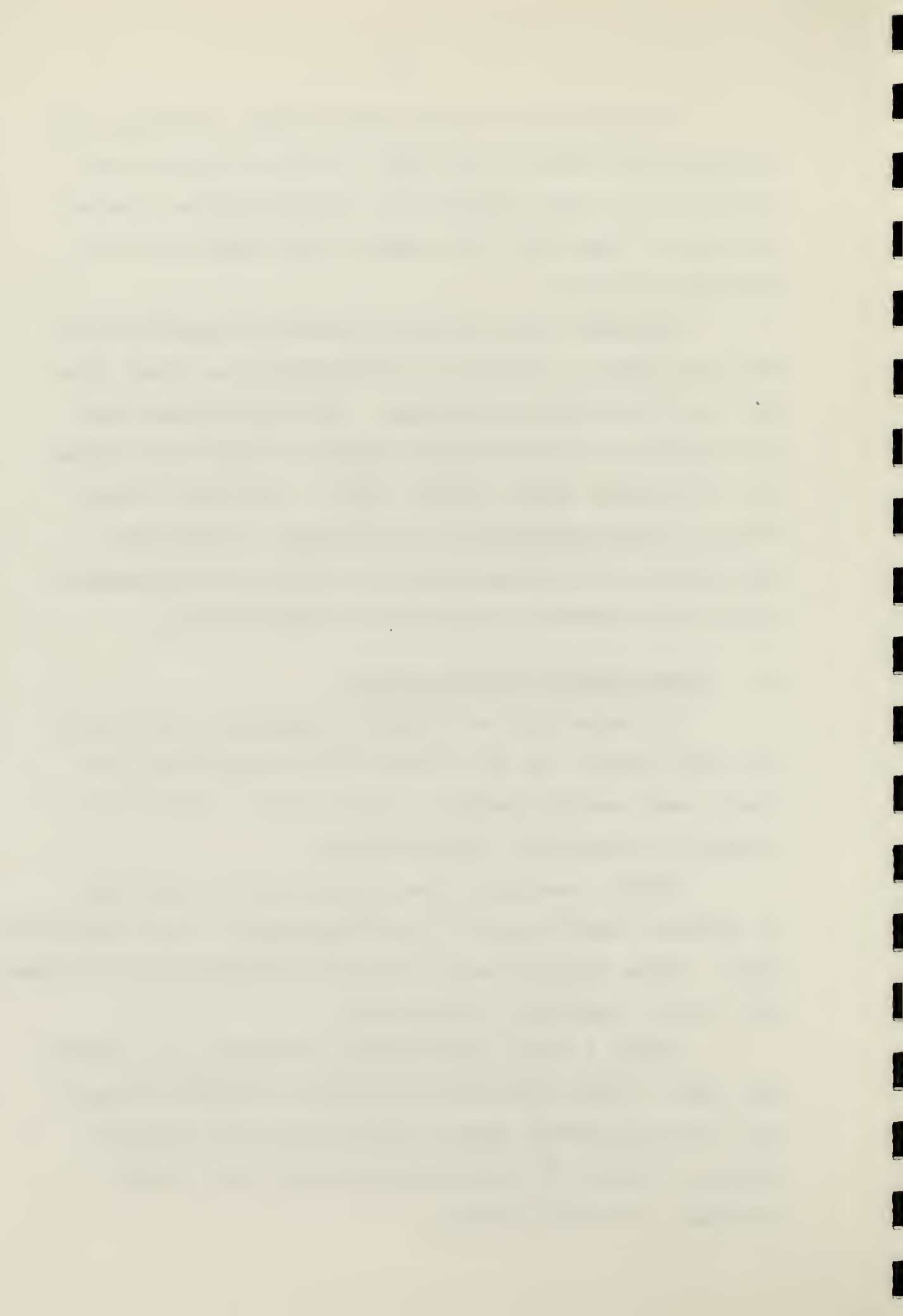
Throughout the entire study period, beginning with the CRA contact, a daily set of photographs was taken from the top of the Buxton lighthouse. These photographs have been used as an atlas of beach changes at Cape Point during the fill period, Dolan, et al. (1974). Additional future study of these photographs is anticipated, particularly with regard to the documentation of storm caused shoreline erosion and overwash, as discussed in Section VIII.

## 2.5. Other Observations and Surveys

The borrow pit was surveyed completely once during the study period, and the southern end was surveyed five times, when possible change was anticipated. Section 3.3 presents an analysis of these changes.

Several beach profiling stations were established on Hatteras Island as part of the development of the vulnerability model. These stations were only visited occasionally and these data are not included in this report.

During a storm, observations of overwash and erosion were made. These observations provided a valuable insight into the relationship between storm nature and resulting damages. Section IV includes these data in the overall assessment of storm activity.

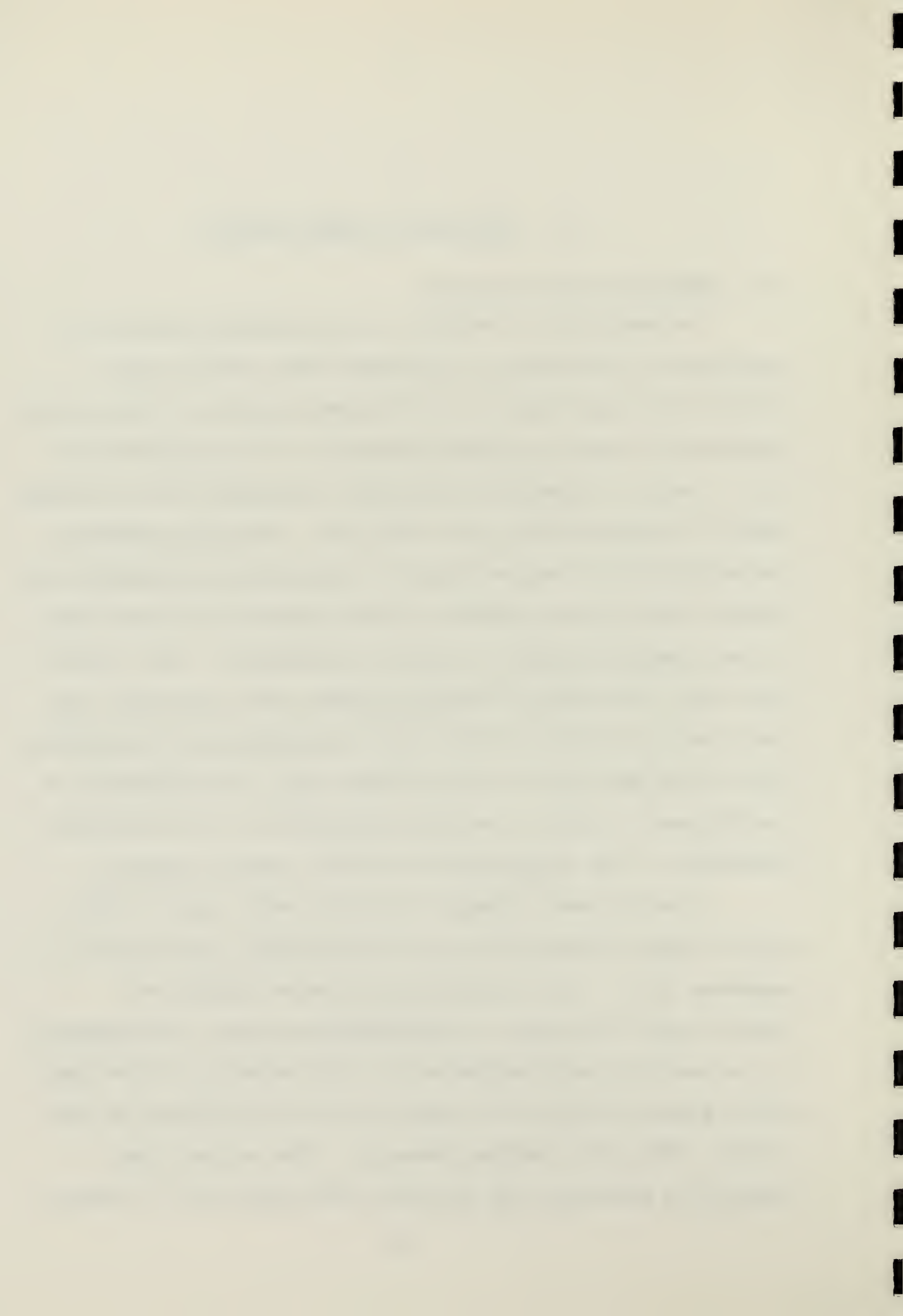


### III. ANALYSIS OF VOLUME CHANGES

#### 3.1. Subaerial Fill Retention

As described in Section II, an extensive program of surveying was undertaken to determine where and how fill material was moved within the nourishment system. This program consisted of beach surveying analogous to that conducted by CRA, as well as intensified fathometer surveying, and a limited number of surveys across the inner bar. The exact procedure for calculation of volume changes is described in Appendix III. Section VIII relates selected volume changes from survey data to area changes measured on aerial photography. This section deals with the volume of material pumped onto the beach; the time history of that material from post-pumping to the present, both on the beach and in the offshore zone; the bathymetry of the offshore at Buxton; and the relationship of environmental parameters to the topography and volume changes offshore.

The contractor pumped 1,250,000 cubic yards of fill onto the beach between stations 2165 and 2240, from June to September 1973. CRA monitored the material pumped and reported that 90 percent of the dredged material was deposited on the beach at each pumping site, with accretion of the beach during pumping raising the figure to over 100 percent at some stations (CRA, Post-pumping Summary). From surveys made immediately preceding and following the completion of pumping,



a determination has been made of the volume of fill which contributed to accretion of the subaerial beach. Table 3.1 shows the results as tabulated for each station, in cubic yards per yard of beachfront. The total accreted above sea level was 646,667 cu yds, an average gain of 243 cu yds/yd within the fill area. At the same time, however, stations to the north and south of the fill area accreted an average of 14 cu yds/yd. This gain can be treated either as representative of the natural summer accretion of the beach, or as the product of redistribution of the fill. The first alternative is preferable for two reasons: 1) the short period elapsed between pre- and post-fill surveys at each station would allow for little redistribution and 2) adoption of this viewpoint leads to a more conservative estimate of material retained on the beach during fill. Taking the position that the mean accretion outside the fill area is a good estimate of natural deposition throughout the study area results in a mean gain due to fill of  $243 - 14 = 229$  cu yds/yd between stations 2165 and 2240, and a total deposition above msl of 608 cu yds, or 49 percent of the material pumped. The remaining material was deposited offshore at each station. (Figure 3.1 demonstrates the relationship of subaerial and subaqueous fill components to each other in the case of station 2200.)

It can be seen from Figure 3.1 that about 50 percent of the material deposited at a station is needed to provide a base for the subaerial accretion. In order to provide a natural beach face slope, more than 50 percent of the material would have to be deposited offshore.



TABLE 3.1

VOLUME OF MATERIAL REMAINING ON THE  
SUBAERIAL BEACH UPON COMPLETION OF PUMPING

| Station | Cu Yds/Yd |
|---------|-----------|
| 2165    | 63        |
| 2170    | 160       |
| 2175    | 270       |
| 2180    | 250       |
| 2185    | 250       |
| 2190    | 210       |
| 2195    | 330       |
| 2200    | 350       |
| 2205    | 230       |
| 2210    | 280       |
| 2215    | 270       |
| 2220    | 300       |
| 2225    | 240       |
| 2230    | 290       |
| 2235    | 260       |
| 2240    | 27        |

|                                                              |                       |
|--------------------------------------------------------------|-----------------------|
| Mean accretion in fill area:                                 | 243 cu yds/yd         |
| Mean accretion outside fill area:                            | 14 cu yds/yd          |
| Net accretion of fill:                                       | 229 cu yds/yd         |
| Total accretion:                                             | 608,480 cubic yards   |
| Total pumped:                                                | 1,250,000 cubic yards |
| Net percent of fill material<br>retained on subaerial beach: | 49 percent            |



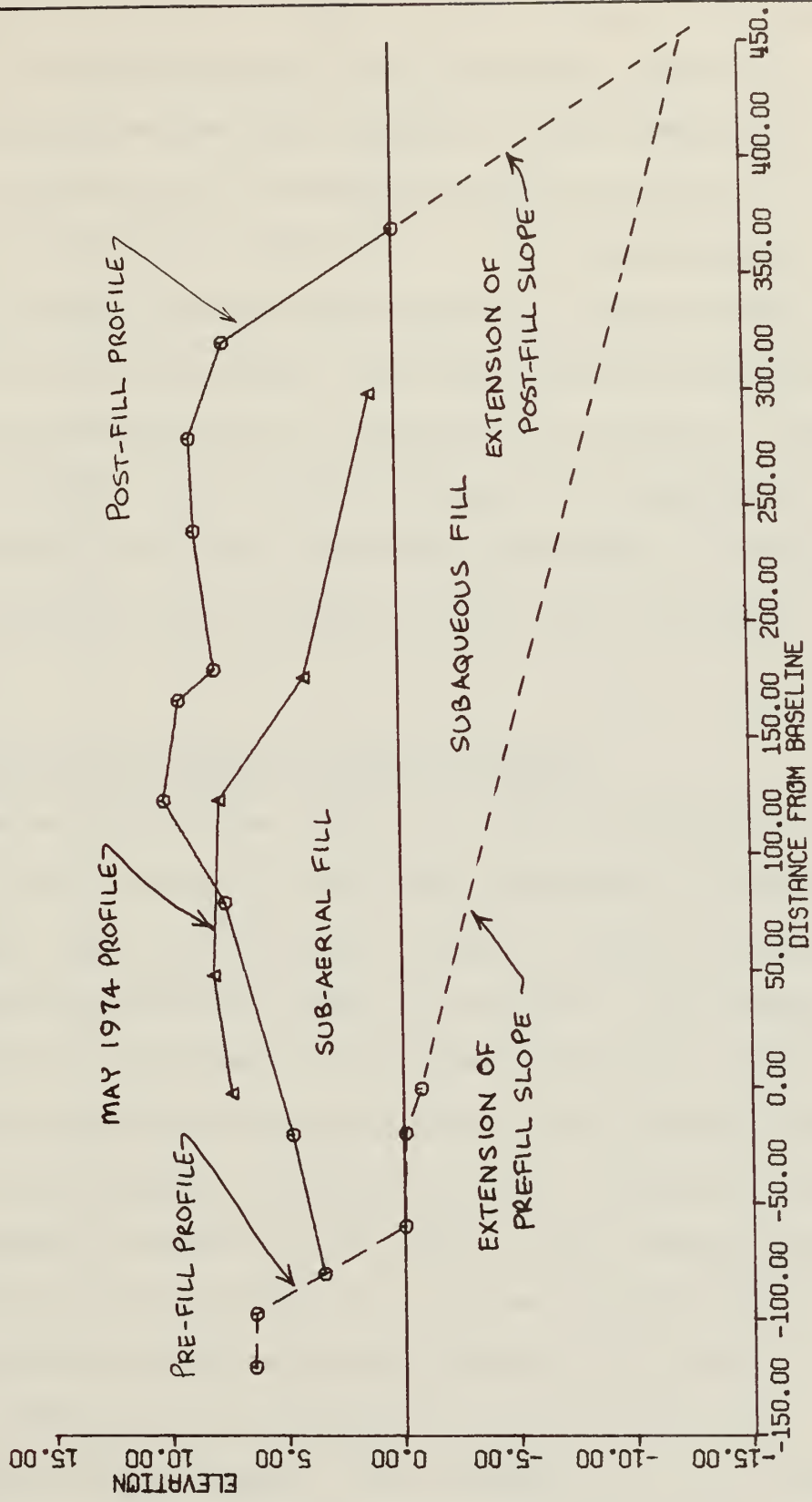


Figure 3.1, Relationships between subaerial and subaqueous fill



Using the data of Table 3.1 as a basis, the volumes of material removed from the fill area during the course of the post-pumping period were compared to the subaerial fill volume at each station to determine percent retention. The results are tabulated in Table 3.2. As of mid-February 1975, 51 percent of the subaerial fill remains in place within the fill area, or 307,343 cu yds. No clear trends in percent retention are evident from an inspection of Table 3.2 and changes in percent are uniform throughout the period of interest. Greater variability in the retention percentages is evident at stations where a small amount of fill was originally deposited.

### 3.2. Statistical Analysis of Beach Changes

The monthly volume changes in cubic yards/yard at stations 2115+20 through 2370+50 were analyzed to determine whether there were characteristic modes of seasonal variation which typified particular groups of stations. The method used is known as eigenvector (orthogonal function) analysis and depends on particular properties of the covariance matrix of a set of simultaneous observations of  $n$  different variables. For the purpose of modeling the type of data treated here, observations of one variable (e.g. volume change) made on different dates can be treated as different variables. One set of observations then consists of monthly values for volume change at one station. The mathematics of the technique are outlined in Hayden, et al. (1975) and described in detail by Gilman (1957). A general description of this type of analysis is found in Davis (1973).



TABLE 3.2

PERCENT RETENTION ON SUBAERIAL BEACH  
BY STATION AS OF FIRST DAY OF MONTH

(Data are for fill area stations only.)

| STA  | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | JAN | FEB | MAR |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 2170 |     | 38  | 20  | 19  | 33  | 32  | 15  | 9   | 26  | 22  | 25  |
| 2175 |     | 56  | 56  | 60  | 55  | 49  | 38  | 46  | 40  | 43  | 52  |
| 2180 |     | 85  | 77  | 82  | 79  | 71  | 61  | 63  | 52  | 63  | 70  |
| 2185 |     | 49  | 53  | 45  | 50  | 44  | 41  | 39  | 46  | 48  | 39  |
| 2190 | 17  | 64  | 46  | 47  | 54  | 39  | 40  | 40  | 36  | 40  | 28  |
| 2200 | 47  | 72  | 71  | 70  | 72  | 67  | 68  | 60  | 61  | 66  | 69  |
| 2205 | 59  | 64  | 52  | 55  | 61  | 57  | 56  | 59  | 65  | 56  | 51  |
| 2210 | 35  | 26  | 31  | 35  | 34  | 32  | 32  | 13  | 29  | 33  | 31  |
| 2215 | 53  | 59  | 61  | 62  | 57  | 60  | 61  | 45  | 56  | 61  | 64  |
| 2220 | 67  | 67  | 68  | 71  | 66  | 69  | 65  | 67  | 173 | 68  | 58  |
| 2225 | 71  | 72  | 73  | 80  | 65  | 58  | 70  | 55  | 59  | 71  | 70  |
| 2230 | 67  | 69  | 64  | 72  | 58  | 59  | 66  | 61  | 55  | 64  | 55  |
| 2235 | 35  | -55 | -39 | -44 | -54 | -70 | -33 | -76 | -71 | 56  | 33  |
| 2240 | 111 | 131 | 153 | 184 | 148 | 125 | 157 | 89  | 98  | 165 | 190 |



Volume changes were first normalized by subtracting the mean seasonal change and the apportionment of the residual variance was then examined. The principal mode of variability (first eigenvector) accounted for only 45 percent of the variance in the volume residuals, Table 3.3. Successive eigenvectors accounted for substantially smaller amounts of variance. By way of comparison, in a system where the variance is highly organized, the first eigenvector commonly accounts for 75 to 80 percent of the variability. Low percentages of variance explained indicate that there are no characteristic groupings among stations. In other words, all stations behaved in similar fashion throughout the post-pumping period insofar as volume changes are concerned.

### 3.3. Offshore Topography

The fathometer surveys conducted during the course of this contract, as well as those carried out on a more limited scale by CRA, have resulted in the production of bathymetric charts such as Figure 3.2. Analysis of these charts shows that there are a number of unique components of the offshore topography at Cape Hatteras which are relatively permanent, although they possess a certain degree of variability in size, shape and position.

The primary feature of the immediate offshore zone is a well-developed outer bar and trough system, with the trough dropping to a depth of roughly 21 feet and the bar rising to a minimum depth of 15 feet. The character of this bar-trough system changes radically at station 2210. To the north, the



TABLE 3.3

PERCENT OF VARIANCE EXPLAINED BY EACH  
OF FIRST 6 EIGENVECTORS

| EIGENVECTOR | % OF<br>VARIANCE<br>EXPLAINED | CUMMULATIVE<br>% OF<br>VARIANCE |
|-------------|-------------------------------|---------------------------------|
| 1           | 24                            | 24                              |
| 2           | 19                            | 43                              |
| 3           | 16                            | 59                              |
| 4           | 15                            | 74                              |
| 5           | 11                            | 85                              |
| 6           | 5                             | 90                              |



Figure 3.2, (Following page) Bathymetric  
map of nourishment area based on beach,  
inshore and fathometer survey data taken  
from 18 July to 2 August 1974.  
One inch equals six hundred feet.





bar is uniform, straight and has approximately equal dimensions. To the south, a considerably more complex situation exists, and the offshore topography has a number of components. Immediately to the south of station 2210, the bar crest height becomes two to five feet lower and the trough widens. This condition is maintained with little variation over long periods of time and may account for the historically severe erosion at station 2210 by allowing waves of greater height to reach the shore instead of breaking on the bar. In the area immediately north of the Lighthouse the bar crest height increases slightly, although the crest is narrower here and sometimes is not appreciably higher than at station 2210. South of the Lighthouse, in the vicinity of stations 2270 to 2280, there sometimes exists a depression within the outer trough up to 27 feet deep. Also in this area the trough widens again and finally ends at about station 2340. The trough in this area can at times display marked meander patterns. At about station 2270, the offshore zone becomes distinctly flatter as Diamond Shoals are approached. Additional bathymetric maps are found in Appendix IV.

#### 3.4. Borrow Pit

The mild storm climate since the end of pumping has resulted in only minor changes in the borrow pit, which was expected to act as a sediment sink during storms. During the February and March storms of 1972, a significant portion of the 1971 Cape Point borrow pit was filled with over 28,000 yards of sediment (Dolan, 1973). Similar filling was



expected to occur in post-nourishment storms; however, there has been only one significant storm since nourishment (Tropical Storm Gilda) and only minor overwash deposition has occurred. Overwash into the pit during Gilda was limited to the southeast corner and the total amount of deposition was small (Dolan, 1973).

The most significant changes in the borrow pit have been tied to the migration of Cape Point. During the summer and fall of 1973, the tip of Cape Point ceased migration to the south and began to retreat to the north and east. This direction of migration is continuing, Figure 3.3. As a result, the southern end of the borrow pit has been eroding northward. The beach separating this portion of the borrow pit from the ocean has retreated just under 400 feet at the southwest corner to over 700 feet at the southeast corner. Portions of the borrow area which were dredged in the summer of 1973 are now seaward of the south beach. A channel between the pit and the ocean is presently open in this area and has been open on and off since spring of 1974.

The retreat of this zone has been accomplished by erosion on the ocean side, overwash across the barrier between the pit and the ocean, and deposition into the south end of the pit, Figure 3.4. Profiles across this area remain relatively similar as retreat takes place. The barrier appears to be rolling over itself with no accretion, but with some erosion. It also appears that there is no net change in the volume of material due to material moving in and out of the gap. The gap has



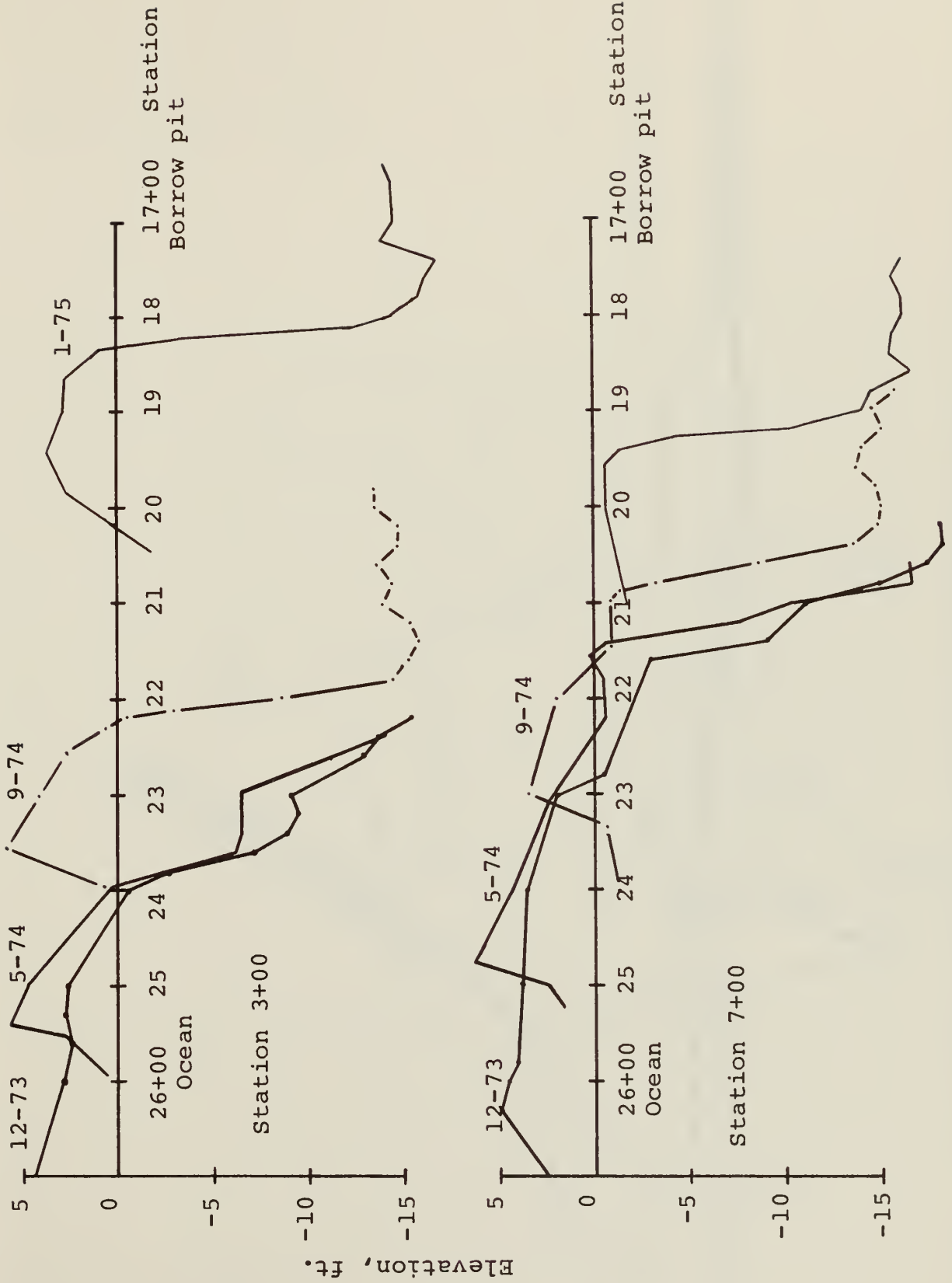


Figure 3.3, Borrow pit retreat on the south side.



8-72 - - - - -  
 2-73 - - - - -  
 6-73 - - - - -  
 8-73 - - - - -  
 6-74 - - - - -  
 12-74 - - - - -

25

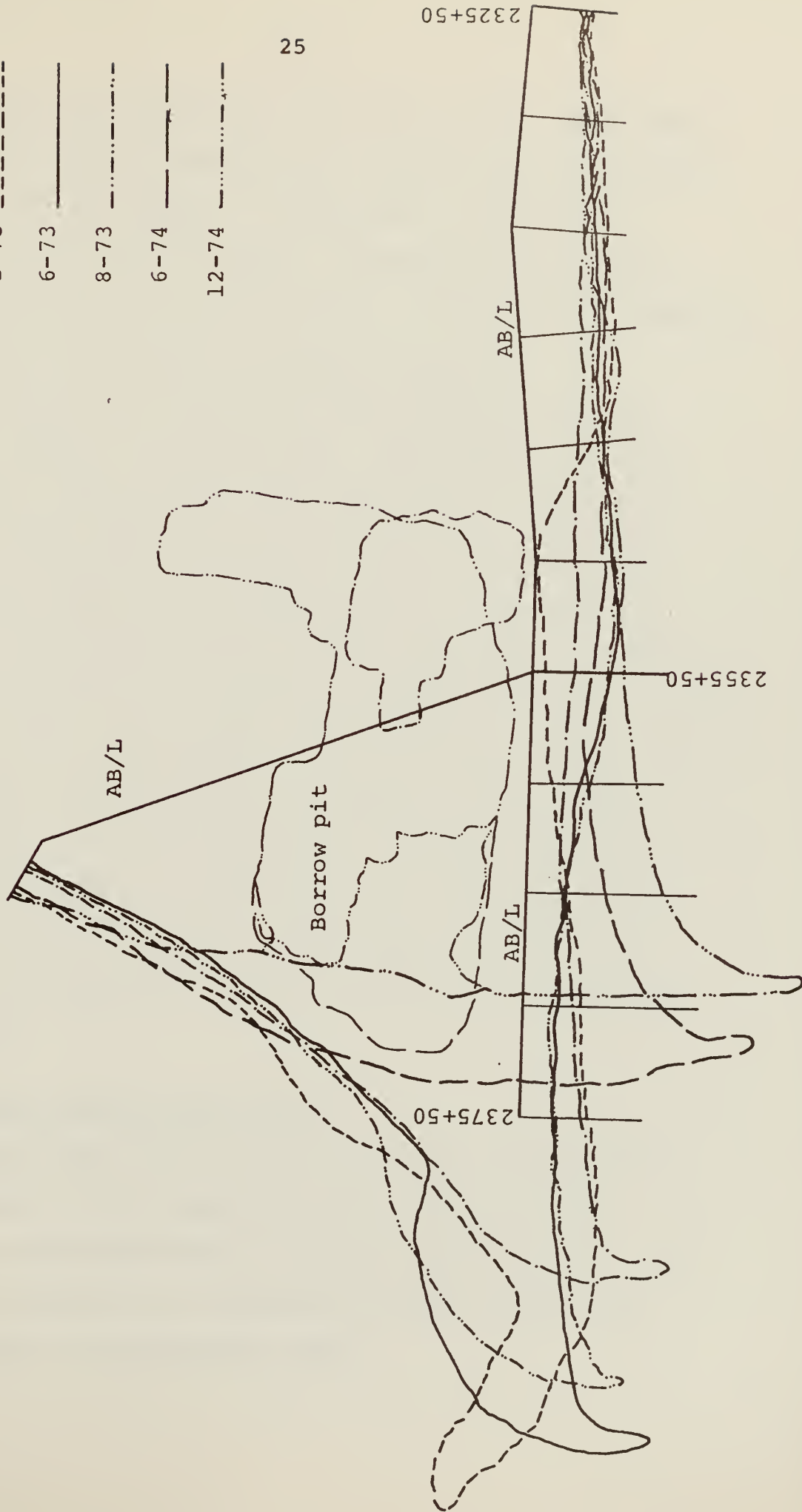


Figure 3.4, Shoreline changes from station 2325+50 to station 2355+50 and at Cape Point, borrow pit retreat, scale 1:8122.



been migrating back and forth in this area and no significant change in the volume of material at a section can be measured after a pass by this channel. Deposition into the pit is balanced by erosion of the barrier separating the pit from the ocean resulting in no net increase in the volume of material in the pit but a decrease in the area of the pit.

The migration of Cape Point has affected only the southern 700 feet of the borrow pit. The remainder of the pit has showed little change since nourishment. Wave and tidal action have eroded the edges of the pit, grading the upper slope and removing the appearance of a steep drop. However, the slope below water is still very steep. A final survey of this area of the borrow pit showed no changes in the volume of material large enough to be detected. Fine, wind-blown sand does cover the coarser sediments on the bottom, but the volume of sand thus deposited is small. There has been some minor overwash into the pit, but this amount has also been too small to result in any appreciable filling. At present, the borrow pit is not a site for any significant sedimentation.

### 3.5. Analysis of Net Volume Change

Volume change data are available on a monthly basis for all stations on the subaerial beach. They are also available for the period June to October 1974 offshore; and in the inner-trough area, a comparison between summer and fall conditions is available for 1974.



Table 3.4 lists the contributions of each element in the overall profile to total volume change since the end of the fill operation. The subaerial beach has accreted considerably in the interval south of station 2265, due primarily to rapid growth of the point between September 1973 and June 1974. Although the point has continued to build seaward since June 1974, the growth has been offset by recession of the shoreline in the area immediately south of the groin field, stations 2295 to 2305. Net accretion has taken place north of the fill area to a lesser degree. Comparison of month by month beach volume change figures for this area, Table 3.4, with net longshore current power data, Table 3.5, indicates that the accretion north of the fill is not the result of northward migration of fill material, but influx of new sediment from the north, since the most significant level of accretion is associated with strong southward currents, while the greatest erosion is associated with northward currents at the LEO site. Within the fill area itself, the major changes have been associated with readjustment of the fill material, the major portion of which occurred after Hurricane Gilda. During the period April 1974 to November 1974, the changes, although generally negative, have been slight in this area. Within the groin area, monthly volume changes are similar in trend to those north of the fill and have the same relationships to the longshore current data. The implication is, therefore, that the groin field has benefited from erosion of the fill material. The shoreline recession south of the groin field since June 1974, a period of strong southward currents, may



TABLE 3.4

MEAN VOLUME CHANGES IN CU YDS/YD OF BEACH  
BY MONTH WITHIN EACH GROUP OF STATIONS

| MONTH              | NORTH  | FILL   | GROINS | POINT  |
|--------------------|--------|--------|--------|--------|
| A. Beach Data      |        |        |        |        |
| APR                | 3.8    | 1.2    | -0.4   | -49.4  |
| MAY                | 1.0    | 2.8    | -3.9   | -4.6   |
| JUN                | -93.6  | -17.5  | -1.5   | -0.1   |
| JUL                | 7.5    | 8.9    | 4.3    | -1.8   |
| AUG                | 1.5    | -12.0  | -3.8   | -18.4  |
| SEP                | 0.1    | -8.3   | -5.5   | -3.4   |
| OCT                | 22.4   | -3.6   | 5.5    | -8.3   |
| NOV                | -6.4   | -19.4  | -3.3   | -1.3   |
| DEC                | -1.7   | 6.0    | -7.1   | -0.0   |
| JAN                | 3.2    | -0.6   | -24.5  | 5.5    |
| B. Fathometer Data |        |        |        |        |
| JUN                | -305.0 | 54.4   | 98.3   | -316.5 |
| JUL                | 94.4   | -217.7 | -113.6 | 109.9  |
| AUG                |        | -212.7 | -114.0 | -15.2  |
| SEP                |        | 1.2    | -39.8  | -156.6 |
| OCT                | -0.4   | 30.5   | 14.9   | -167.6 |
| C. Inshore Data    |        |        |        |        |
| JUN/OCT            | n.d.   | -4.8   | n.d.   | n.d.   |

## Stations:

|             |           |             |             |
|-------------|-----------|-------------|-------------|
| 2115 - 2165 | North End | 2245 - 2260 | Groin Field |
| 2170 - 2240 | Fill      | 2265 - 2365 | Point       |

n.d. = no data



TABLE 3.5

MEAN LONGSHORE CURRENT POWER FROM LEO  
DATA AT STATION 2200 DURING PERIODS  
PRECEDING END OF MONTH SURVEYS.

| MONTH | $v^2$<br>f.p.s. <sup>2</sup> | MEAN<br>WAVE<br>HT.<br>(ft.) |
|-------|------------------------------|------------------------------|
| MAY   | -1.4                         | 1.6                          |
| JUN   | -1.1                         | 2.7                          |
| JUL   | +0.4                         | 2.0                          |
| AUG   | +1.2                         | 1.9                          |
| SEP   | +2.8                         | 2.6                          |
| OCT   | +3.6                         | 2.1                          |
| NOV   | +2.6                         | 2.2                          |

Positive values denote southward  
moving currents.



be due to trapping of fill material in the groin field at the expense of the Point.

Only the October 1974 and July 1974 inner trough surveys were suitably arranged for volume changes to be computed. When pro-rated on a monthly basis, these data are similar to the beach and offshore means (Table 3.3). Inshore data are not available outside the fill area.

Fathometer surveys indicate a general loss of material throughout most of the study area and throughout the period of the surveys. The net positive mean change in the area of the point is due to a large gain in the period February to May 1974, during the rapid building and northward migration of Cape Point.

Knowledge of the direction of movement of the fill material is of primary importance to understanding the impact of nourishment at Cape Hatteras. A serious handicap in the effort to determine transport paths for the fill material is the lack of complete pre- and post-fill fathometer data as well as limited quantities of data relating the offshore profile to the beach profile. In the discussion which follows, several assumptions are made which enable the computation of net volume transport for the post-pumping period. The figures thus derived are at best a first approximation, however, the overall picture presented is of value in interpreting the effectiveness of the fill project. In order for calculations to be feasible, it must be assumed that the mean volume change at each station based on the longest run of data available is representative



of, and can be extended to cover, the full post-pumping time interval. No problem arises in this regard with respect to the subaerial beach, for which continuous data are available. Nor does there seem to be any difficulty in the case of fathometer data which are available for 10 out of a total of 16 post-pumping months at most stations. The nearshore data, however, cover only one four month period at a handful of stations within the fill area and therefore projections based on volumes computed from these data cannot reasonably be used in calculating net volume differences. Unfortunately, neglecting the nearshore data leads directly to the assumption that the nearshore, in the mean, has not changed appreciably since post-pumping. While there is no overwhelming evidence to support this view, it nonetheless allows the analysis to proceed. In the event that the nearshore data were included, some provision would have to be made regarding values for these data outside the fill area. Since volume changes vary considerably along the beach, the most expedient and reasonable course appears to be that of assuming a negligible contribution from the nearshore zone.

With these assumptions it is possible to calculate total volume changes in cubic yards since post-fill for each portion of the project, i.e., offshore and subaerial beach, with each subdivided further into North End (stas. 22150 → 2165), Fill (stas. 2170 → 2240), Groins (stas. 2245 → 2260) and Point (stas. 2265 → 2365) subsets. The totals were computed according to the formula:



$$\Delta V = (116.67)(16)\bar{\bar{V}}_n$$

where

166.67 = number of yards between stations

16 = number of months since post-fill

$\bar{\bar{V}}$  = mean monthly change averaged over  
both time and subset

n = number of stations in subset

The results and a suggested schematization of sediment flows are shown in Figure 3.5.

It is clear from Figure 3.5 that there is a trend from negative to positive volume changes from north to south, both on the beach and offshore, with large gains of material on the Point, and generally large losses of material in the Fill and North End. There is a net loss over the 16 month period of 771,003 cubic yards of material. Thus, of 1,250,000 cubic yards originally pumped, only about 40 percent is still in the system. The net longshore drift, as inferred from current measurements, has been to the south, although seasonal periods of northward drift do exist. It is presumed that any material lost to the south will eventually end up in Diamond Shoals and Figure 3.5 reflects this. Other components of the volume conservation model include an unknown amount of longshore drift entering the system from the north and moving either onto the shoals or offshore. Also, seasonal onshore/offshore components have been ignored for simplicity, and in any case are probably balanced and contribute little to the long term pattern.

The implications of this analysis for the future of the nourishment project are threefold: first, it has been



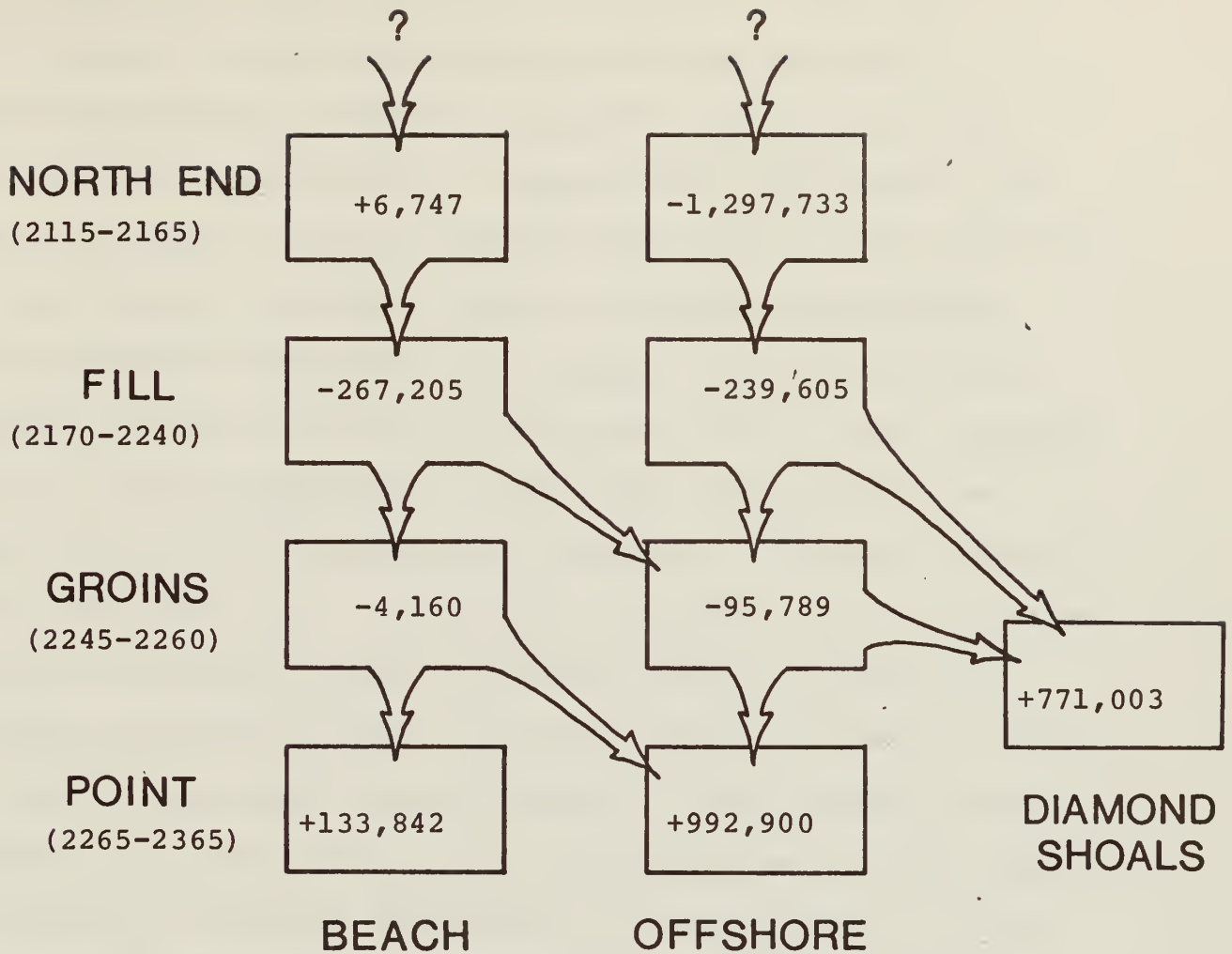


Figure 3.5, Schematization of the inferred pattern of sediment transport in the study area between completion of pumping and 1 February 1975. Figures in boxes are total volume change in cubic yards. Arrows indicate direction of net movement of material, excluding seasonal on and offshore movements.



established with some certainty that material lost from the fill area has not been deposited at the base of a new equilibrium slope, as had been suggested, and indeed hoped, at the start of the project. Instead, the fill material has become involved in a more comprehensive change in the structure of Cape Hatteras involving a general shoaling and buildup of the Diamond Shoals/Cape Point complex, apparently at the expense of material offshore of stations 2115 to 2260. Second, and as a direct consequence of the first implication, the North End and Fill area are now fronted by a steeper, offshore slope and lower bar. If this trend continues, and if the storm climate at Hatteras reaches its former level of intensity, previous estimates of fill "life" may require revision. Third, in view of the overall trend observed in this analysis, there appears to be some question as to whether material moved south to the point, either on or offshore, is really still "in the system" for the purposes of estimating fill effectiveness. This material appears now to be tied up in the Point, and unless a reversal of the processes now active takes place, can be considered permanently lost to the beach at Buxton.

In the sixteen months since the completion of the fill operation, net longshore drift toward the south has removed 60 percent of the original fill material and deposited it on Cape Point and Diamond Shoals. Of the 608,480 cubic yards remaining on the subaerial beach at the completion of fill, 51 percent remains on the beach as of mid February 1975.

Concurrently, with the expected reworking of the fill material, dramatic changes have taken place in the general



organization of the offshore bar-trough system, leading to a deepening of the area north of station 2260 and shoaling of the area near the Point.



#### IV. STORM SUMMARY

During the second year following beach nourishment, Cape Hatteras has experienced a relatively mild storm season. Only 20 extra-tropical storms generating deep water waves in excess of five feet occurred. Dolan and Hayden (1973) have computed the average number of storms for a 30-year period through 1973. The annual average for these storms is 33.6, and thus it is clear that 1974 was appreciably less severe than the mean, as was 1972. Since March 1, 1974, six storms have had sufficient size to cause some overtopping of the storm berm, i.e. overwash and/or some beach erosion. Figure 4.1 shows the recurrence intervals for the 20 storms in 1974. All but the December storm were within the yearly interval. This latter storm, although longer, did not have an appreciable impact on the beach.

Table 4.1 summarizes the storm parameters and the resulting subaerial beach erosion for the six storms during the contract period. The data suggests that the relationship between wave height and direction and resulting erosion is extremely complex. A preliminary study has been initiated in an attempt to relate these parameters, but no results are available for this report.

The April storm is of particular interest because of the large amount of material eroded for the relatively



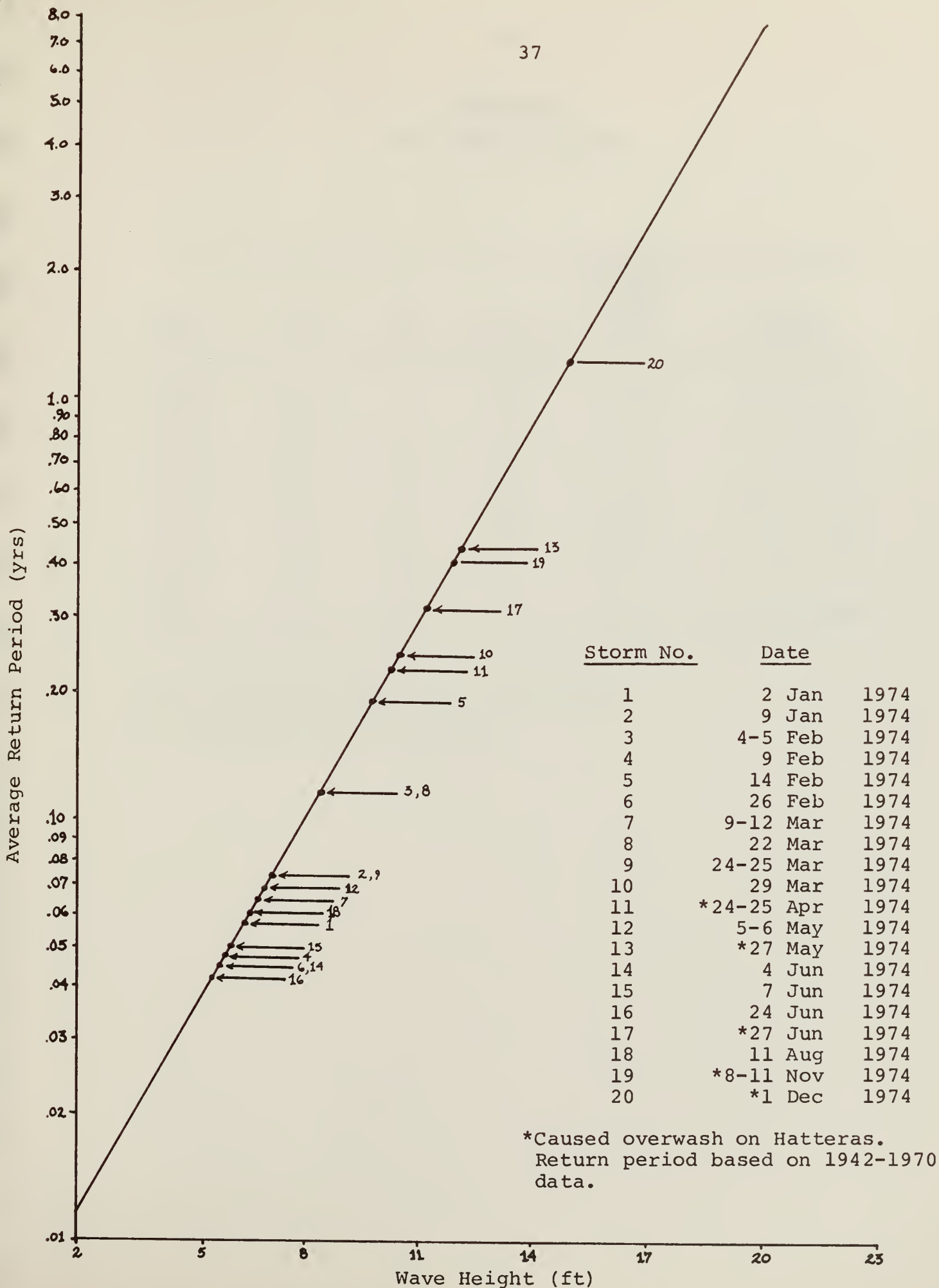


Figure 4.1, Storm recurrence interval.



TABLE 4.1

## 1974 STORM ACTIVITY

| Date  | H <sub>o</sub><br>ft | H<br>ft | Direction | Volume<br>Change<br>cu yd/<br>yd | Survey<br>Dates |
|-------|----------------------|---------|-----------|----------------------------------|-----------------|
| 3/29  | 10.4                 | ---     | SE        | + 2.05                           | 3/27- 4/02      |
| 4/24  | 10.3                 | 4.5     | N         | -43.45                           | 4/02- 4/30      |
| 5/28  | 12.1                 | 5.0     | NE        | + 8.27                           | 5/08- 6/07      |
| 6/23  | 11.4                 | 2.5     | NNE       | -21.33                           | 6/20- 7/03      |
| 11/10 | 12.0                 | 4.0     | N         | -17.71                           | 11/05-11/13     |
| 12/01 | 15.0                 | 4.0     | S         | - 4.32                           | 11/25-12/03     |

H<sub>o</sub> = hindcasted deep water wave height

H = LEO observed wave height



small deep water wave height. One clue to this large impact might be the wave climate between survey dates, inasmuch as the reported volume changes integrates over the entire survey period.

The importance of wave direction is apparent from both the March and December storms. The latter storm had the longest hindcasted wave height, but only a small amount of erosion. The wave refraction model discussed in Section VIII should provide some insight into the significance of this parameter.



## V. ECOLOGICAL IMPACT

The distribution of Emerita talpoida, the common mole crab, was determined by CRA to be an effective indicator of the ecological impact of the nourishment project on the biota of the surf and swash zones. The premise was that a significant change in the feeding habits or distribution patterns of Emerita talpoida would indicate a negative influence of the nourishment on the ecological balance of the surf and swash zones. Sampling of the mole crab populations during the nourishment period indicated a very short period of disruption of the feeding habits as evidenced in the migration of crabs away from the area of discharge and an immediate resurgence of the populations within a few tidal cycles of the movement of the area of discharge. It was further reported that the effect of the discharge was to cause the migration of the animals rather than their mortality (Hayden, 1974).

At the end of the nourishment period, the method of sampling was altered slightly in accord with optimum procedures established during the nourishment period. A sample was collected at each of 15 mile post survey stations, spaced between 1/2 and 1/4 mile apart, over an area from Mile Post 39 to Cape Point, which encompassed the entire nourishment area, as well as a substantial distance on both sides



(Figure 1.1). Of the 15 stations, 5 were within the nourishment area, 4 were located north of the nourishment area, and 6 were located to the south of the nourishment area. A total of 31 separate surveys were taken on an approximately bi-weekly basis from November 1973 through February 1975. A standard shovelfull of sand was taken from the part of the swash which was shown to have the greatest concentration of Emerita and the number of organisms noted. Zero and low counts were reaffirmed by multiple samples to preclude the possibility of inaccurately placed samples.

A total of 465 samples was taken. Frequency histograms were plotted for the number of organisms counted per sample for both the total sample population, Figure 5.1, and for the summer population, Figure 5.2, on the basis that the summer population would give a better estimate of the frequency distribution. As can be seen from Figure 5.3, E. talpoida are present on the beach in significant numbers only during the warmer months. There is a large jump in the numbers of organisms found in the late spring corresponding to an increase in water temperature. Two peaks in the time distribution, one in early August and the other in late November, correspond roughly to the semi-annual reproductive cycle for E. talpoida described by Wharton (1942). The two minima preceding the peaks correspond to what he described as a mating swim in which the organisms leave the beach and inhabit the nearshore zone. During this time, smaller numbers of organisms can be found in the swash zone which account for



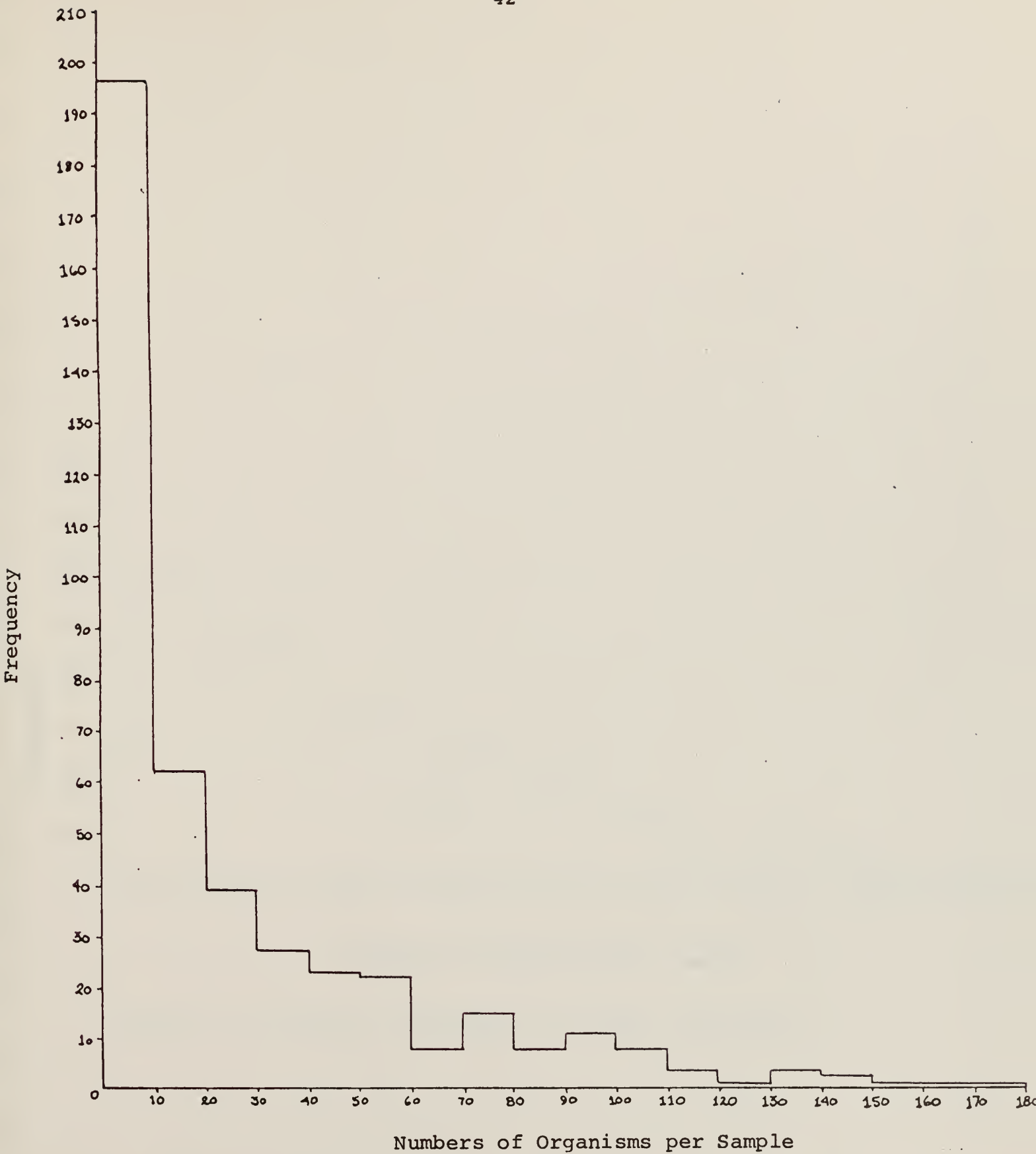


Figure 5.1, Frequency histogram for total population.



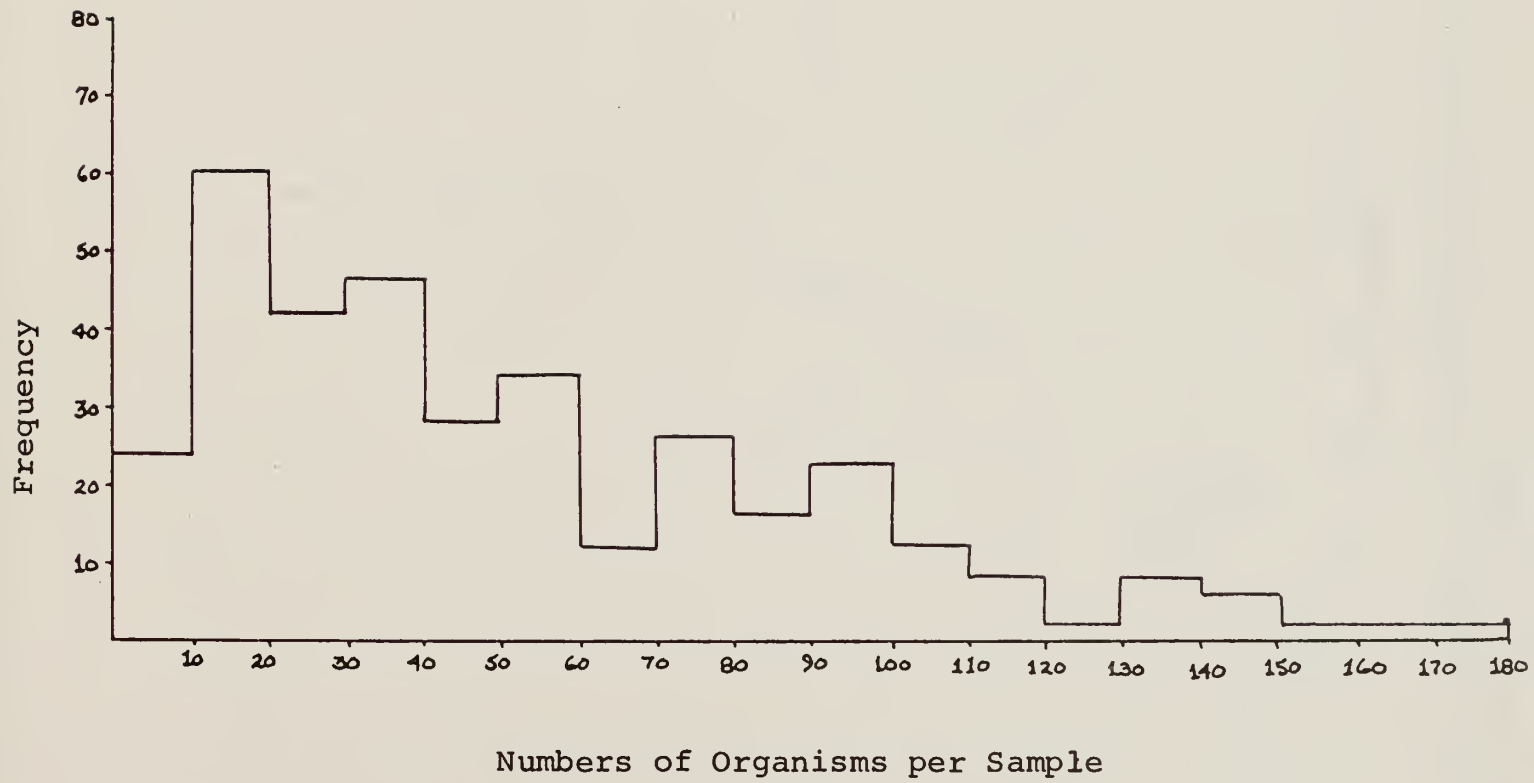


Figure 5.2, Frequency histogram for summer population.



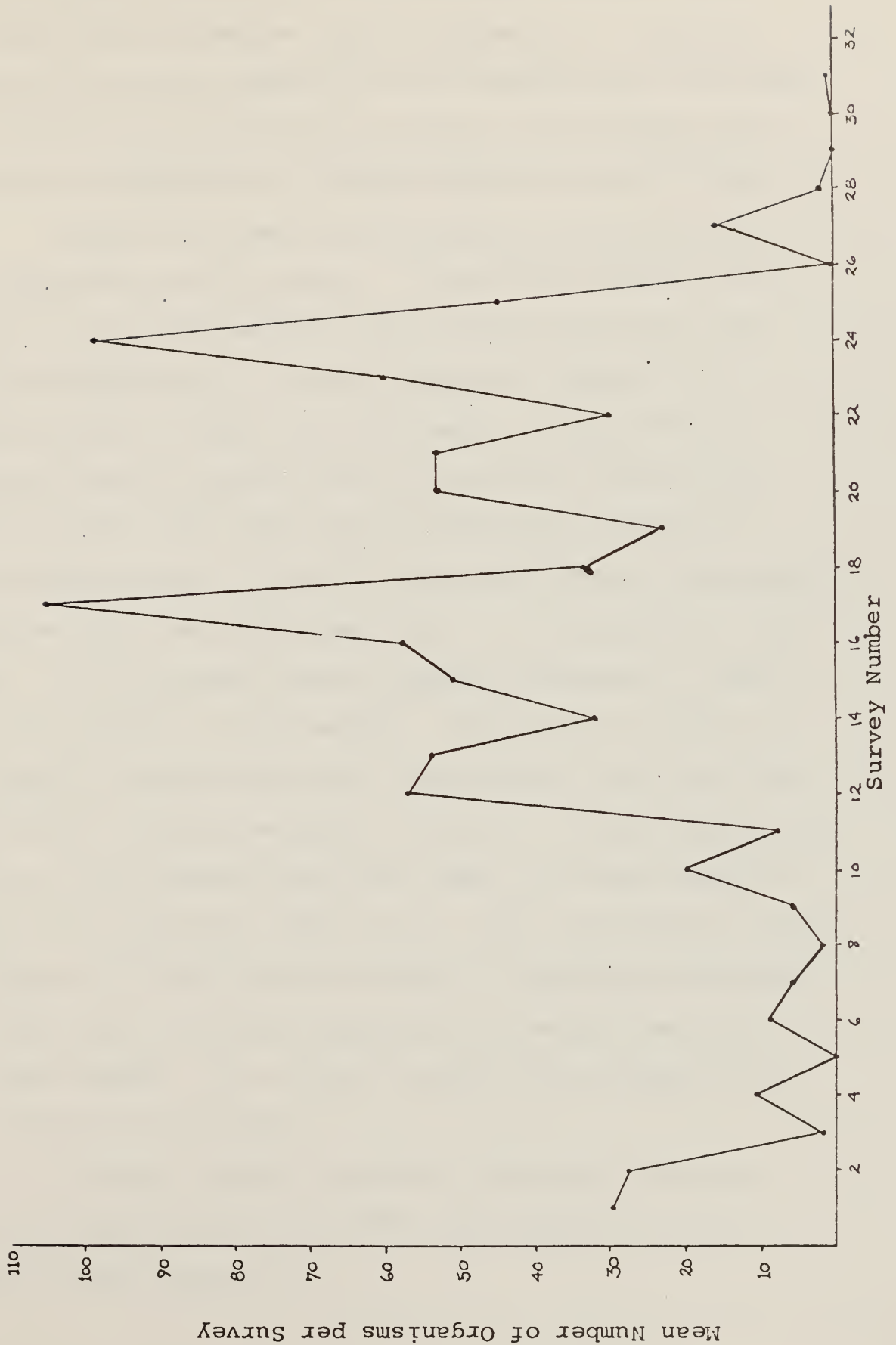


Figure 5.3, Distribution of mean numbers of organisms per survey throughout the sampling period. Samples are numbered consecutively beginning 15 November 1973 and are approximately bi-weekly.



the low sample numbers. It was further found by Wharton that the mature organisms tend to aggregate in colonies while the young are generally well dispersed over the beach. This explains the occasional occurrence of extremely high numbers of organisms in a single sample as shown in Table 5.1.

Figure 5.4 shows the distribution of annual means of organisms along the beach. A significant break in the numbers can be seen between Mile Post 39.5 and Mile Post 40.0 corresponding to a major topographic break in the beach system. At this point the beach is restricted by barrier dunes to the north and is broad and unrestricted to the south. The inshore bar-trough system changes at this point as well. It can be shown from aerial photography that the inner bar approaches shore and disappears at this point. It is evident that the complex processes of these two areas differ to some degree. Analysis of variance of the Emerita samples shows that the stations from Mile Post 40.0 south, although variable, belong to a single population whereas those stations from Mile Post 39.5 north belong to a separate population (Table 5.2). This can further be seen in Figure 5.5 where the mean number of organisms per sample per mile post was plotted against the standard deviation of those samples. The results clearly are separable into two distinct populations.

A similar method was used to separate the winter from the summer populations with equal success, shown in Table 5.3 and Figure 5.6.



TABLE 5.1  
TABULATED VALUES OF EMERITA TALPOIDA SAMPLES

| Sample Numbers | Mile Post Numbers |      |      |      |      |       |      |       |      |       |      |      |      |      |      |  |
|----------------|-------------------|------|------|------|------|-------|------|-------|------|-------|------|------|------|------|------|--|
|                | 39.0              | 39.5 | 40.0 | 40.5 | 41.0 | 41.25 | 41.5 | 41.75 | 42.0 | 42.25 | 42.5 | 43.0 | 43.5 | 44.0 | 44.5 |  |
| 1              | 0.                | 0.   | 53.  | 0.   | 50.  | 74.   | 46.  | 13.   | 15.  | 42.   | 43.  | 2.   | 108. | 0.   | 44.5 |  |
| 2              | 20.               | 12.  | 57.  | 6.   | 4.   | 28.   | 10.  | 27.   | 15.  | 56.   | 46.  | 31.  | 14.  | 30.  | 64.  |  |
| 3              | 0.                | 1.   | 7.   | 1.   | 3.   | 2.    | 0.   | 3.    | 0.   | 4.    | 2.   | 0.   | 1.   | 2.   | 1.   |  |
| 4              | 5.                | 4.   | 16.  | 6.   | 10.  | 9.    | 4.   | 7.    | 23.  | 19.   | 6.   | 4.   | 32.  | 17.  | 8.   |  |
| 5              | 2.                | 0.   | 1.   | 0.   | 0.   | 0.    | 1.   | 0.    | 0.   | 0.    | 0.   | 0.   | 0.   | 0.   | 1.   |  |
| 6              | 4.                | 12.  | 4.   | 7.   | 20.  | 5.    | 8.   | 24.   | 4.   | 7.    | 6.   | 2.   | 14.  | 5.   | 16.  |  |
| 7              | 1.                | 3.   | 1.   | 8.   | 12.  | 5.    | 7.   | 2.    | 3.   | 4.    | 6.   | 8.   | 8.   | 11.  | 14.  |  |
| 8              | 1.                | 0.   | 1.   | 1.   | 0.   | 0.    | 0.   | 1.    | 0.   | 0.    | 5.   | 1.   | 2.   | 9.   | 15.  |  |
| 9              | 2.                | 3.   | 1.   | 4.   | 3.   | 5.    | 5.   | 2.    | 3.   | 4.    | 2.   | 6.   | 12.  | 14.  | 23.  |  |
| 10             | 4.                | 4.   | 6.   | 66.  | 15.  | 3.    | 33.  | 49.   | 26.  | 9.    | 17.  | 4.   | 14.  | 45.  | 5.   |  |
| 11             | 6.                | 10.  | 8.   | 4.   | 5.   | 3.    | 8.   | 3.    | 5.   | 14.   | 9.   | 4.   | 11.  | 22.  | 10.  |  |
| 12             | 8.                | 5.   | 16.  | 25.  | 4.   | 23.   | 170. | 52.   | 138. | 50.   | 93.  | 34.  | 111. | 30.  | 90.  |  |
| 13             | 1.                | 78.  | 114. | 20.  | 73.  | 76.   | 14.  | 88.   | 85.  | 56.   | 53.  | 45.  | 57.  | 39.  | 12.  |  |
| 14             | 2.                | 5.   | 29.  | 52.  | 48.  | 23.   | 38.  | 32.   | 41.  | 12.   | 62.  | 17.  | 54.  | 33.  | 17.  |  |
| 15             | 40.               | 19.  | 50.  | 34.  | 51.  | 93.   | 37.  | 19.   | 43.  | 4.    | 5.   | 0.   | 127. | 83.  | 155. |  |
| 16             | 24.               | 28.  | 31.  | 83.  | 85.  | 29.   | 37.  | 70.   | 34.  | 91.   | 35.  | 28.  | 237. | 14.  | 45.  |  |
| 17             | 42.               | 57.  | 17.  | 369. | 53.  | 98.   | 73.  | 217.  | 22.  | 58.   | 83.  | 32.  | 130. | 97.  | 227. |  |
| 18             | 1.                | 23.  | 39.  | 30.  | 24.  | 46.   | 15.  | 74.   | 52.  | 14.   | 37.  | 37.  | 9.   | 79.  | 12.  |  |
| 19             | 8.                | 7.   | 5.   | 23.  | 6.   | 27.   | 12.  | 10.   | 79.  | 26.   | 2.   | 46.  | 3.   | 75.  | 16.  |  |
| 20             | 11.               | 29.  | 263. | 40.  | 24.  | 63.   | 31.  | 60.   | 90.  | 45.   | 35.  | 13.  | 14.  | 16.  | 56.  |  |
| 21             | 20.               | 16.  | 13.  | 104. | 96.  | 21.   | 11.  | 116.  | 93.  | 41.   | 27.  | 34.  | 18.  | 80.  | 105. |  |
| 22             | 4.                | 10.  | 21.  | 51.  | 12.  | 62.   | 27.  | 44.   | 28.  | 25.   | 109. | 10.  | 16.  | 8.   | 19.  |  |
| 23             | 0.                | 5.   | 9.   | 79.  | 58.  | 30.   | 139. | 88.   | 145. | 168.  | 42.  | 55.  | 33.  | 26.  | 24.  |  |
| 24             | 44.               | 6.   | 76.  | 147. | 71.  | 52.   | 101. | 135.  | 35.  | 67.   | 99.  | 376. | 106. | 110. | 55.  |  |
| 25             | 21.               | 0.   | 3.   | 10.  | 144. | 16.   | 72.  | 92.   | 19.  | 19.   | 47.  | 72.  | 103. | 12.  | 42.  |  |
| 26             | 0.                | 0.   | 0.   | 0.   | 0.   | 0.    | 0.   | 0.    | 0.   | 0.    | 0.   | 1.   | 0.   | 0.   | 1.   |  |
| 27             | 23.               | 7.   | 9.   | 22.  | 107. | 18.   | 4.   | 5.    | 1.   | 22.   | 16.  | 5.   | 2.   | 2.   | 0.   |  |
| 28             | 3.                | 2.   | 0.   | 0.   | 0.   | 1.    | 4.   | 0.    | 0.   | 0.    | 0.   | 0.   | 1.   | 3.   | 9.   |  |
| 29             | 0.                | 0.   | 0.   | 0.   | 4.   | 1.    | 0.   | 0.    | 0.   | 0.    | 0.   | 0.   | 0.   | 0.   | 0.   |  |
| 30             | 0.                | 0.   | 0.   | 0.   | 0.   | 0.    | 0.   | 0.    | 2.   | 0.    | 0.   | 0.   | 0.   | 0.   | 3.   |  |
| 31             | 0.                | 0.   | 0.   | 0.   | 3.   | 0.    | 0.   | 0.    | 1.   | 3.    | 1.   | 0.   | 1.   | 2.   | 0.   |  |

Sample Numbers



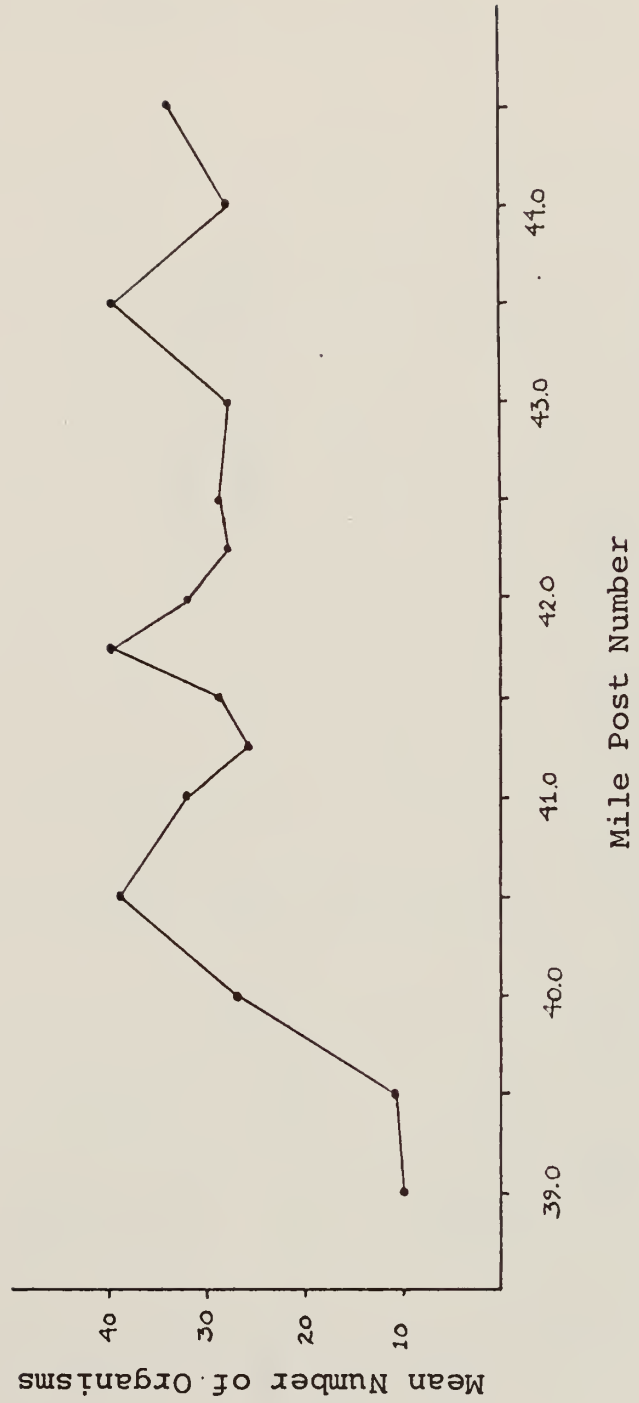


Figure 5.4, Distribution of annual means along the beach.



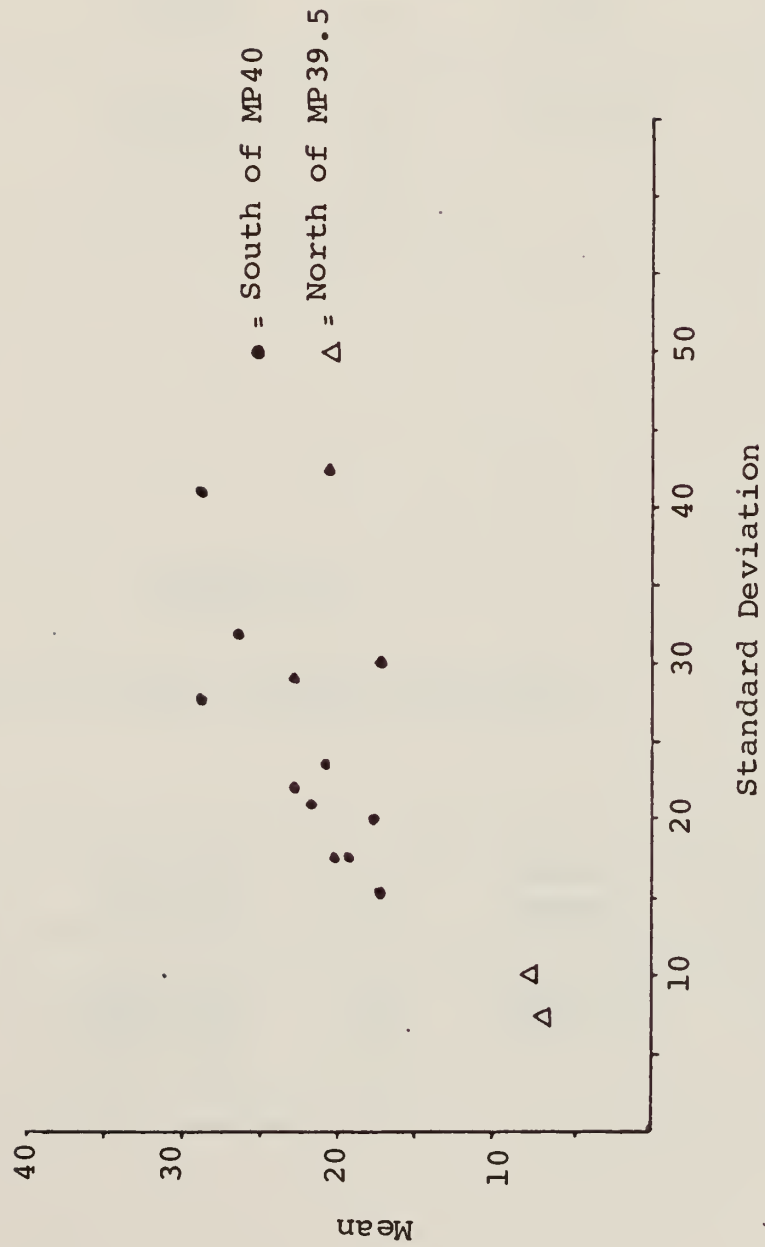


Figure 5.5, Mean number of rganisms per sample per milepost vs. standard deviation of those samples.



TABLE 5.2

## ANOVA OF NORTH-SOUTH POPULATIONS

|                | Sum of<br>Squares | d.f.      | Mean<br>Square | F<br>ratio |
|----------------|-------------------|-----------|----------------|------------|
| Category Means | 15180.07          | 1         | 15180.07       | 15.57      |
| Within Groups  | <u>52650.14</u>   | <u>54</u> | 975.00         | 4          |
| Total          | 67830.21          | 55        |                |            |

TABLE 5.3

## ANOVA OF WINTER-SUMMER POPULATIONS

|                | Sum of<br>Squares | d.f.      | Mean<br>Square | F<br>ratio |
|----------------|-------------------|-----------|----------------|------------|
| Category Means | 65448.10          | 1         | 65448.10       | 25.16      |
| Within Groups  | <u>228929.56</u>  | <u>88</u> | 2601.47        | 4          |
| Total          | 294377.66         | 89        |                |            |



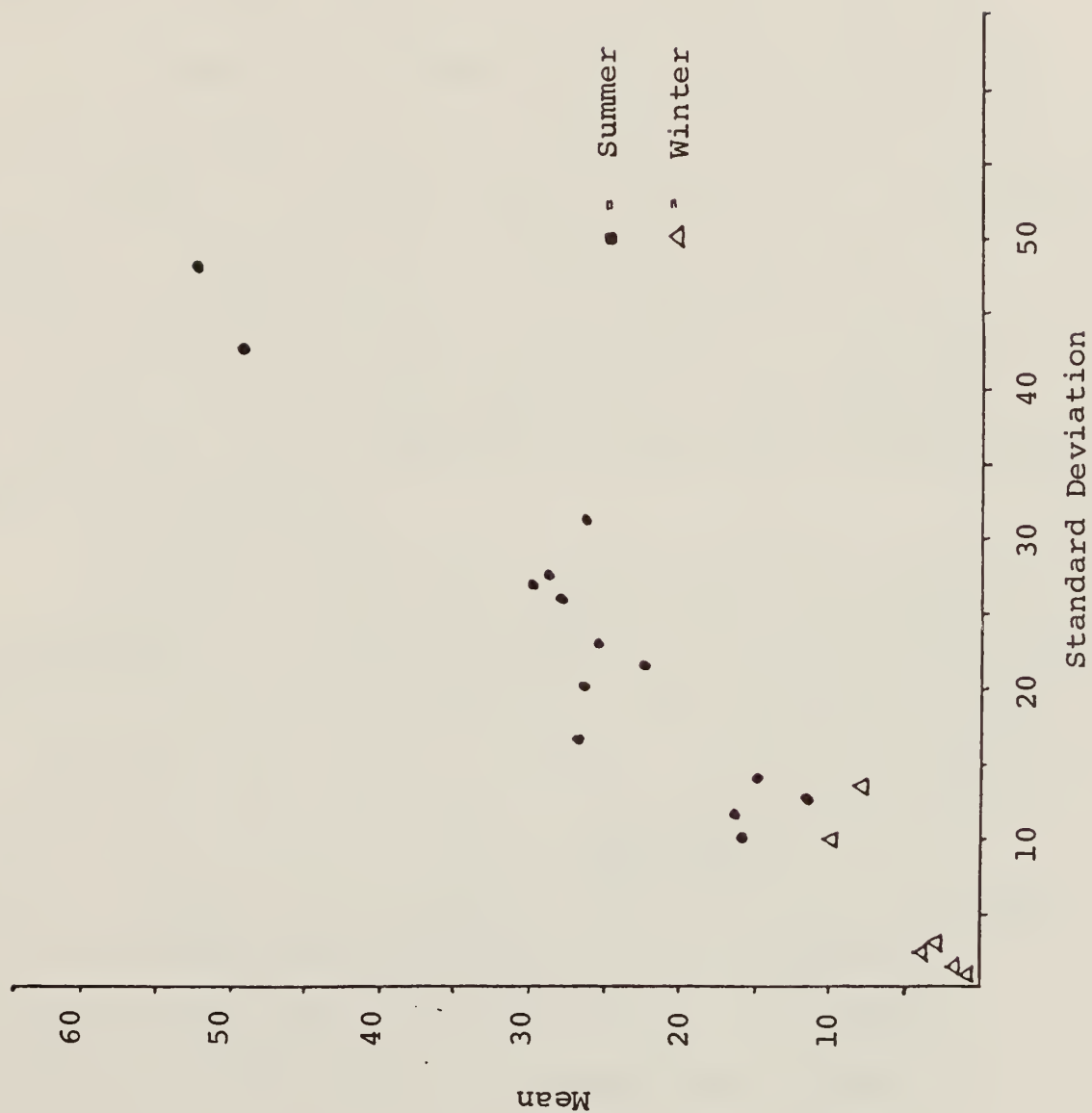


Figure 5.6, Mean number of organisms per survey vs. standard deviation of those surveys.



Simultaneous with the organism counts, sediment samples were taken and the grain sizes analyzed with the nourishment samples described in Section VI. These data enable one to undertake a correlation and possibly a regression analysis between the two variables, grain size being the independent variable and the number of organisms being the dependent variable. Figure 5.7 shows the scatter plot of numbers of organisms against grain size. Correlation analysis of the data gives a correlation coefficient of 0.06 for the summer samples and a correlation coefficient of 0.01 for the total sample population. This indicates that the grain size of the beach and the number of organisms present are independent.

Analysis of these data suggests that the selection of E. talpoida as a sensitive indicator of altered ecological balance, by virtue of its position in the food chain of the surf and swash zone, was well founded. Variation in samples along the beach show that while E. talpoida may in fact respond to changes in processes, within the fill area itself there is no detectable difference in the distribution patterns from the areas without the fill. The temporal distributions of the organism, corresponding closely to a previous study also done on the Outer Banks of North Carolina, indicate that there has been no alteration of the behavioral patterns (Wharton, 1942). Finally, a correlation analysis of the number of organisms with grain size supports the null hypothesis that any change in grain size within the natural limits of the Cape Hatteras beach system would not



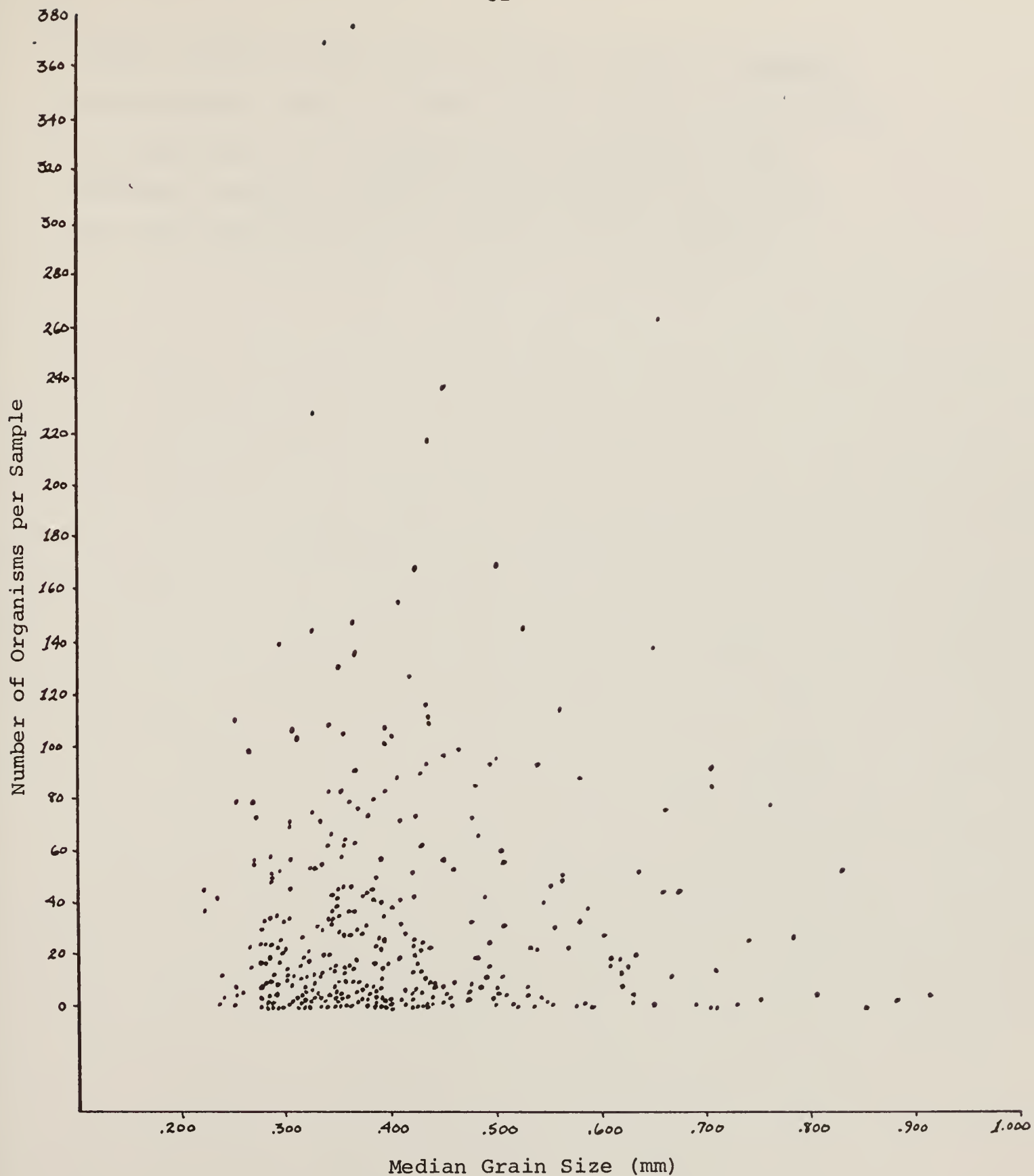


Figure 5.7, Scatter Plot of Numbers of Organisms per Sample vs. Median Grain Size for that Sample.



cause a change in the distributions or numbers of Emerita.  
The conclusion then, in light of this analysis, must be that  
the nourishment of the beach at Cape Hatteras National  
Seashore has had no impact on the ecological balance of  
the surf and swash zones in the area of the project.



## VI. ANALYSIS OF SEDIMENT

### 6.1. Overfill Determination

One factor in a successful nourishment project is the characteristics of the material pumped onto the beach. The natural beach material characteristics are a result of the sediment sources and the wave climate. The morphological and sedimentological features of the natural beach are adjusted by the wave climate into a quasi-equilibrium state which can rapidly respond to changes in wave energy. Given the limitations of the sediment sources, the sediment size distribution on the natural beach is a result of the wave climate and represents the best adjustment to the energy conditions.

For these reasons, fill material which is exactly like the native material is the best to use in terms of maximum retention. Material that is coarser may remain on the beach longer; however, the morphological adjustment to the larger grain sizes could make the beach less suitable for recreation, CERC (1973). Finer material will be moved offshore and lost more rapidly than "natural" material.

Although fill material with characteristics similar to the beach to be nourished is the first choice, a source for this material is often difficult to find within an economic distance. Along most barrier beaches, the material

# THEORY OF THE EARTH

## CHAPTER I

### OF THE ORIGIN OF THE EARTH

THE EARTH, as we see it, is a globe, or sphere, of a very great size, and of a very great weight.

It is composed of a solid mass of matter, which is called the crust.

The crust is the outermost layer of the earth, and is the part which we see.

It is divided into two parts, the land and the sea.

The land is the part of the earth which is covered with soil, and is the part which we walk upon.

The sea is the part of the earth which is covered with water, and is the part which we sail upon.

The land and the sea are separated by mountains, rivers, and bays.

The mountains are the high parts of the land, and the rivers are the streams of water which flow from them.

The bays are the parts of the sea which are enclosed by land.

The land and the sea are not always in the same position, but they are constantly changing.

Some parts of the land are rising, and some parts are sinking.

Some parts of the sea are becoming land, and some parts of the land are becoming sea.

The land and the sea are constantly changing, and they will continue to change for ever.

The land and the sea are constantly changing, and they will continue to change for ever.

The land and the sea are constantly changing, and they will continue to change for ever.

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most like beach material is found either on the beach or offshore. Neither of these areas is especially suitable for a borrow area. Sediments on the back of the barrier and in the sound are generally finer. There are some depositional features, such as spits, tidal deltas, and points, scattered along barrier islands which are more suitable for borrow areas. Since these features are deposited under energy conditions more like those affecting the beach, the grain size will be more nearly like that of the beach. If such a feature is located near the nourishment area, it could be the ideal source.

If material of the right size is not available, or is some distance from the project area, the most economical means of placing the desired amount of sand on the beach may be by overfilling with finer sediment. While it is expected that the finer fraction of the material will be sorted out and washed away by waves, the coarser fraction should remain and assume a distribution similar to the natural one. Placing twice as much sand on the beach as project design calls for may leave the proper amount on the beach if the finer half is expected to wash away.

Krumbein and James (1965) have developed an empirical technique of determining if the borrow material is suitable for use on the natural beach and how much overfilling will be needed, if any. The normalized ( $\phi$  transformed) distribution of sampled borrow material grain sizes is compared with the normalized natural distribution. If the size distribution of



fill material is different from the natural material size distribution, the proportion of borrow material which must be removed to produce a modified distribution the same as the native distribution is computed. The overfill ration ( $R_{crit}$ ) can be computed from the following formula (for phi transformed data):

$$R_{crit} = \frac{\sigma_B}{\sigma_N} e^{-\left[ \frac{(M_N - M_B)^2}{2(\sigma_N^2 - \sigma_B^2)} \right]}$$

where

$\sigma$  = Standard deviation                      B = Borrow material

M = Mean                                              N = Native material

If the borrow material is better sorted than the natural material, the distributions cannot be matched. In this case, borrow material with a mean smaller than the native mean can be expected to be very unstable while borrow material coarser than native can be expected to be stable. When the borrow material is not as well sorted as the native, an overfill ratio can be computed although it will likely be an overestimate if the borrow material is coarser than the native.

The source of borrow material for the Buxton Beach Nourishment Project was Cape Point. This depositional feature south of the project area was chosen because it had been deposited under similar energy conditions. A pre-nourishment analysis and analysis during pumping of the grain sizes in the area showed that the mean borrow grain size was almost identical to the native grain size (Dolan, 1973). However,



no quantitative comparison of the native and borrow distributions was carried out to determine if differences in the distributions could account for some of the post-fill sediment loss.

During the course of the present study, the means of 100 as pumped samples and 100 native samples were chosen from the time period when the first pass was made up the beach (April to June, 1973). On each day of pumping, the three "as pumped" nourishment samples were selected and the three northernmost beach samples were chosen. These beach samples were always determined, in the field, to be out of the influence of the pumped sand.

The phi means and the phi standard deviations of both groups were determined and  $R_{crit}$  was calculated. The phi mean of the native group was 1.64 with a standard deviation of 0.302. The borrow mean was 1.67 with a standard deviation of 0.260. The computed value of  $R_{crit}$  was 1.1, for an overfill ratio near 1. The two distributions are almost identical. The borrow material is slightly smaller and slightly better sorted than the native material; however, it is not likely that these very small differences could account for the nourishment losses. The borrow material is virtually the same as the native material and was an excellent choice for fill.

## 6.2. Grain Size Analysis

Differences between the native sand and the nourishment material at Buxton are minimal. This is ideal for the project, but it makes it virtually impossible to trace the movement of



the pumped material on the basis of its characteristics. Some type of tracer sand could have been introduced along with the nourishment material; however, large quantities would have been needed. In addition to the added expense and possible safety hazards (if the tracer were radioactive), long-term sediment transport volume determinations are not yet possible from a tracer study, CERC (1973). The direction and magnitude of long-term sediment transport for this project could only be determined by volumetric changes over time (see Section III).

Sand samples were collected from five main zones along the beach, at the mid-tide point, in the inner trough, on the inner bar, in the outer trough, and on the outer bar. An attempt was made to collect the trough samples from the deepest part of the trough and the bar samples from the bar crest. Samples at each point were collected each time a profile over that zone was surveyed. For that reason, a large number of mid-tide samples were collected with fewer samples for the other zones. The inner bar and trough were least sampled since these were the most difficult to survey.

An analysis of variance for several sets of sample means was computed to examine changes in sediment characteristics along the beach and through time. In addition to testing for a significant difference in the variance between groups from the variance within groups, the means were compared and grouped into statistically homogenous subsets. The Duncan Multiple Range Test was used to generate these subsets at a 5 percent



significance level, Kendall and Stuart (1968). Using such a multiple comparison test is an a posteriori means of testing for significant differences between groups, Wells and Ludwick (1974).

Mean grain size showed a steady decrease moving from the mid-tide zone to the outer bar, Figure 6.1. Mid-tide samples were significantly coarser than any of the other zones. The outer bar was also significantly finer than the inner trough, but there were no other statistically significant differences in the means. Variability in grain size was greatest in the troughs.

Monthly mean mid-tide grain size showed a steady decline from the start of this project until September, with an increase in size during the fall and early winter, Figure 6.2. There was a significant difference at the 5 percent level in the variance between months, Table 6.1, with some of the summer months differing significantly from the spring and late fall months. A significant seasonal trend does appear to be present. Variance in grain size was least during the summer period, reflecting the generally calmer wave conditions.

Variations in mid-tide grain size along the project area were greater between stations than within stations Table 6.1. From Figure 6.3, it can be seen that the material in the northern half of the project tended to be coarser than that in the southern half. A rather sharp divide in size seemed to take place between station 2245+50 and station



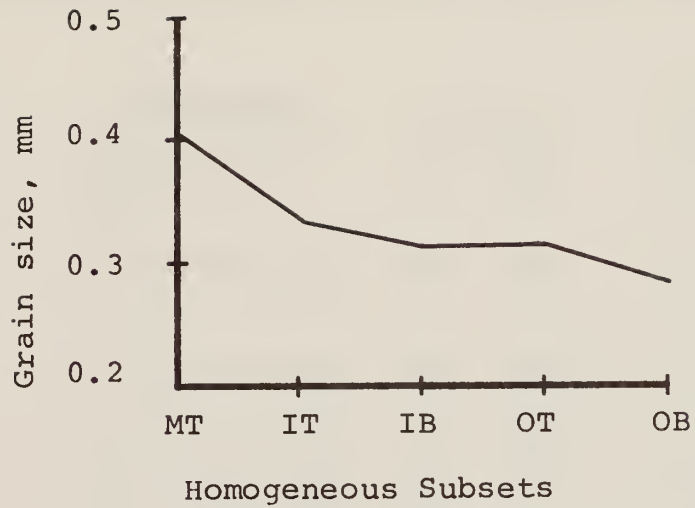


Figure 6.1, Mean grain size by zone.

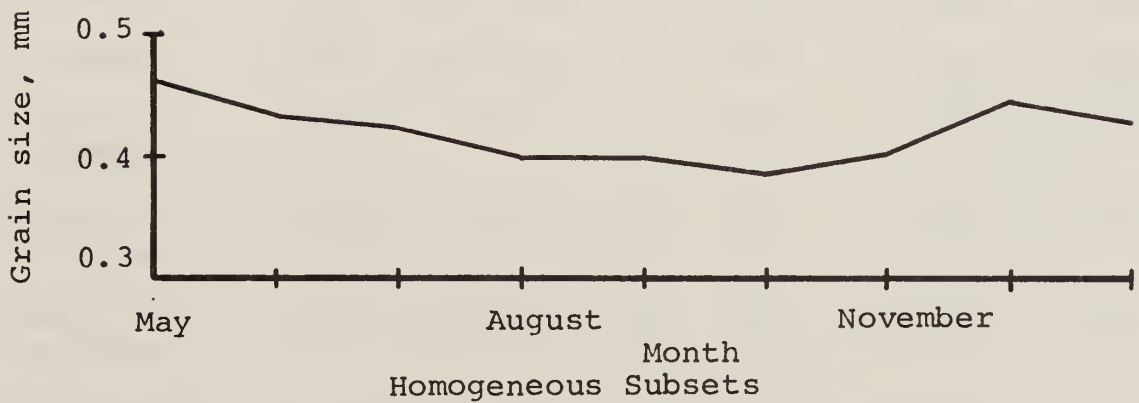


Figure 6.2, Mean monthly midtide grain size.



TABLE 6.1

ANALYSIS OF VARIANCE FOR MEAN SEDIMENT DATA SETS

| <u>Period</u>     | <u>Groupings</u>      | <u>D.F.</u> | <u>F Ratio</u> | <u>F Prob.</u> |
|-------------------|-----------------------|-------------|----------------|----------------|
| April to December | MT, IB, IT,<br>OB, OT | 4; 1596     | 40.449         | 0.000          |
| April to December | MT by stations        | 51; 789     | 2.509          | 0.000          |
| Summer            | MT by stations        | 51; 477     | 1.171          | 0.203          |
| Winter            | MT by stations        | 51; 260     | 2.358          | 0.000          |
| April             | MT by stations        | 49; 8       | 0.688          | 0.801          |
| May               | MT by stations        | 49; 19      | 1.391          | 0.218          |
| June              | MT by stations        | 51; 37      | 0.818          | 0.750          |
| July              | MT by stations        | 51; 77      | 0.857          | 0.720          |
| August            | MT by stations        | 51; 63      | 1.296          | 0.163          |
| September         | MT by stations        | 51; 0       |                |                |
| October           | MT by stations        | 51; 92      | 1.729          | 0.011          |
| November          | MT by stations        | 51; 58      | 1.083          | 0.383          |
| December          | MT by stations        | 50; 24      | 1.711          | 0.077          |
| April to December | IT by 4 zones         | 3; 101      | 0.517          | 0.671          |
| April to December | IB by 4 zones         | 3; 99       | 1.431          | 0.238          |
| April to December | OT by stations        | 50; 178     | 3.783          | 0.000          |
| April to December | OB by stations        | 50; 209     | 10.064         | 0.000          |
| All Stations      | MT by months          | 8; 878      | 2.378          | 0.016          |

MT = Mid-Tide

IT = Inner Trough

IB = Inner Bar

OT = Outer Trough

OB = Outer Bar



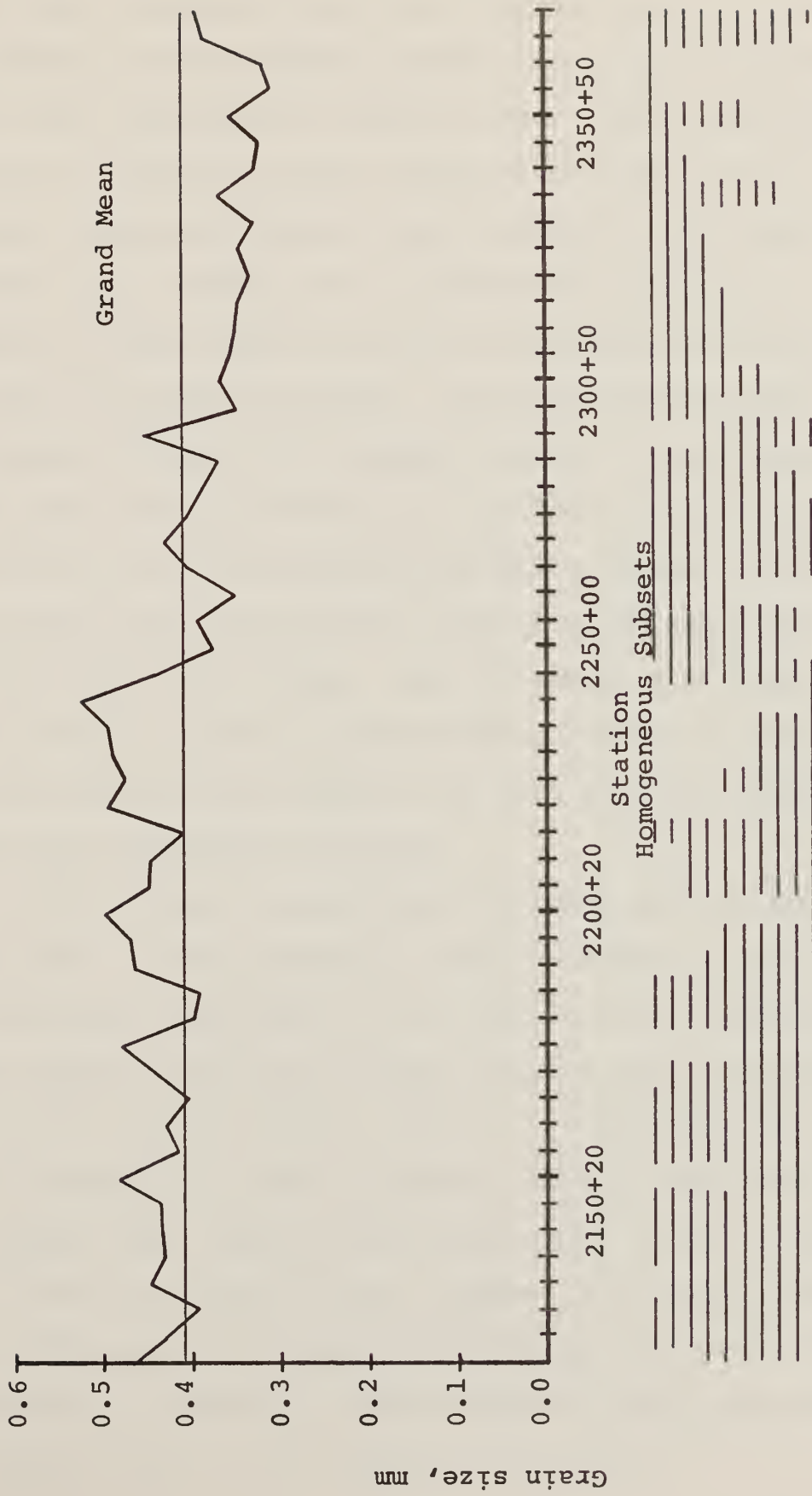


Figure 6.3, Mean midtide grain size.



2250+00, at the center of the groin field. North of this point, only 4 stations were finer than the mean of all mid-tide samples for the project period while only two stations to the south were coarser than the mean. The large number of stations lead to a rather confusing pattern in the homogenous subsets; however, the trend seen in the means holds for those stations that differed statistically.

In general, those stations north of the groins to the northern fill area are grouped together, and those stations south of the southern overwash are grouped together. Those stations in the groin area and south of the groins in the southern overwash area are intermediate between the coarser northern material and the finer southern sand, but are not statistically different from either group. The two stations at Cape Point, several stations in the northern portion of the fill area, and the stations north of the fill area also seem to occupy this intermediate position.

With a yearly trend along the beach and a trend through time, a more detailed, monthly analysis of the changes along the beach was needed. On a monthly basis, variation between stations was significantly greater than within stations for only one month, October, Table 6.1. The smaller F ratios are partly a result of smaller sample sizes, but they also suggest that variability in grain size is not as great over a shorter period of time. However, the yearly trends of mid-tide grain size along the beach were also seen in each month's data. Generally, stations south of the groin area have smaller material than those to the north.



In an attempt to negate the influence of the small sample sizes on the analysis of variance, mid-tide data were grouped into two larger sets, summer and winter. These sets were determined from the analysis of grain sizes through time. June, July, August, September, and October were grouped together to form the summer set and the other months formed the winter set.

The analysis of variance for the summer set along the beach revealed no statistically significant difference. The smaller grain sizes during the summer, especially north of the groins, Figure 6.4, and the lower variance account for this lack of significance. Notice, however, that the along the beach trend in the means still remains. North of the groins grain size remains generally greater than the mean summer grain size and south of the groins it remains generally smaller. Stations north of the groins to the northern portion of the fill area tend to have the coarsest material while the finest material is between the southern portion of the overwash south of the lighthouse and the embayment at Cape Point.

The F probability for the winter set is 0.00. Winter mean grain size north of the groins was almost always greater than the summer grain size at the same station. South of the groins, winter grain size was smaller than the summer size in two-thirds of the cases. The winter trend was similar to the summer trend and amplified it at most stations.

Reversals in the trends apparent in the yearly mean grain sizes are not seen in the seasonal or monthly data.



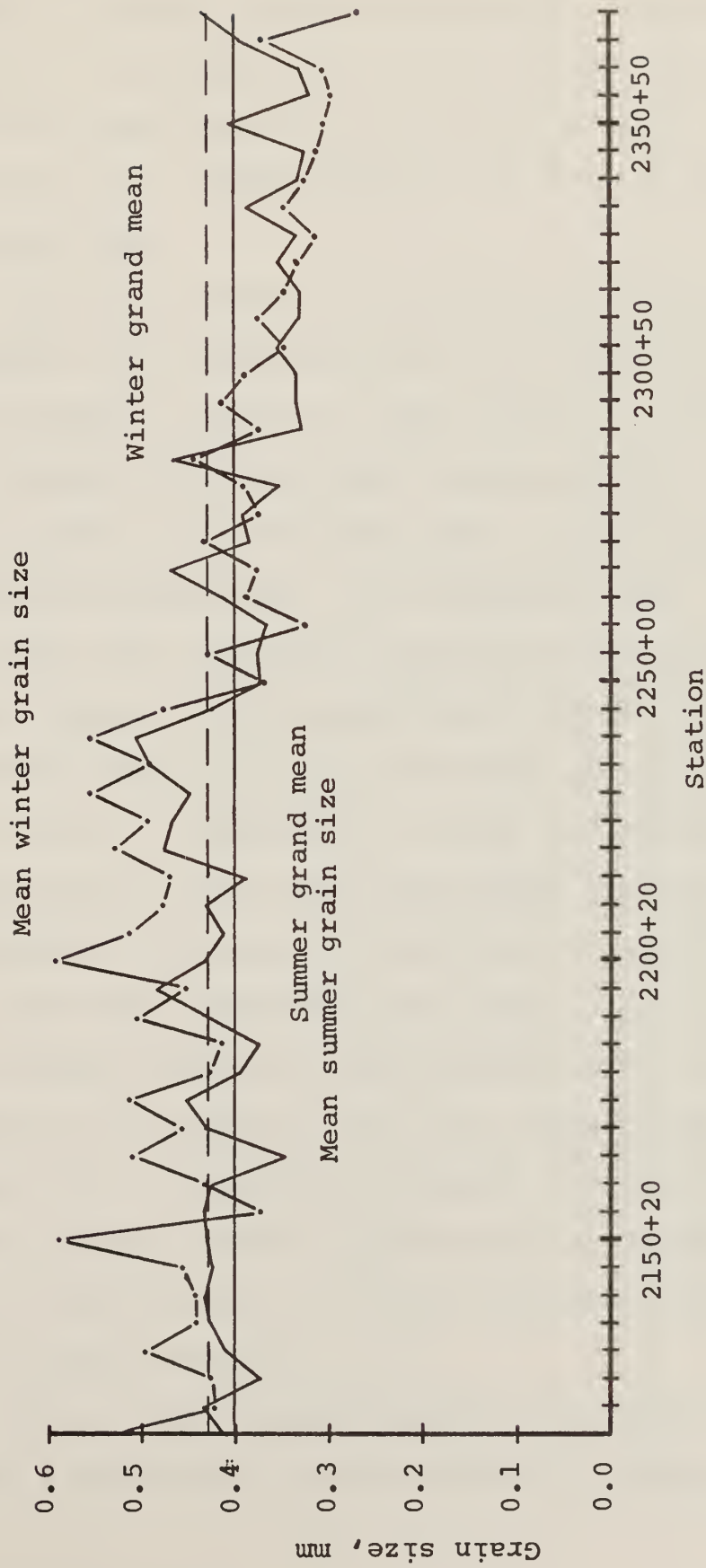


Figure 6.4, Mean midtide grain size, summer and winter.



Differences in sizes were most pronounced during the winter and appear to account for the statistically significant difference in the yearly data, but the summer months tended to follow the same pattern as the winter months. The area of the groins was a marked dividing point in the grain sizes on the beach face.

Station by station, along the beach analysis of the inner trough or bar sediment could not be made because of the small number of samples at each station. Likewise, an analysis through time would have little meaning. An arbitrary grouping in each set of data was made, and an analysis of these groups was performed. The groupings were: north of the fill area, the fill area, the groin area, and south of the groin. Statistically significant differences did not exist between these groupings for either the inner trough or the inner bar. Figure 6.5 is a plot of mean grain size along the beach for both the inner trough and bar. The high variability was partly a result of the small sample sizes. There was a trend for finer grain sizes in the northern project area and in the northern half of the fill area. North of the groins and in the southern half of the nourishment area, the coarsest material was found with smaller but highly variable grain sizes south of the groins. Once again, it appears that the groin area is a transition zone from coarser to finer material.

With a larger sample size for the outer trough and outer bar, a station by station analysis of changes along the



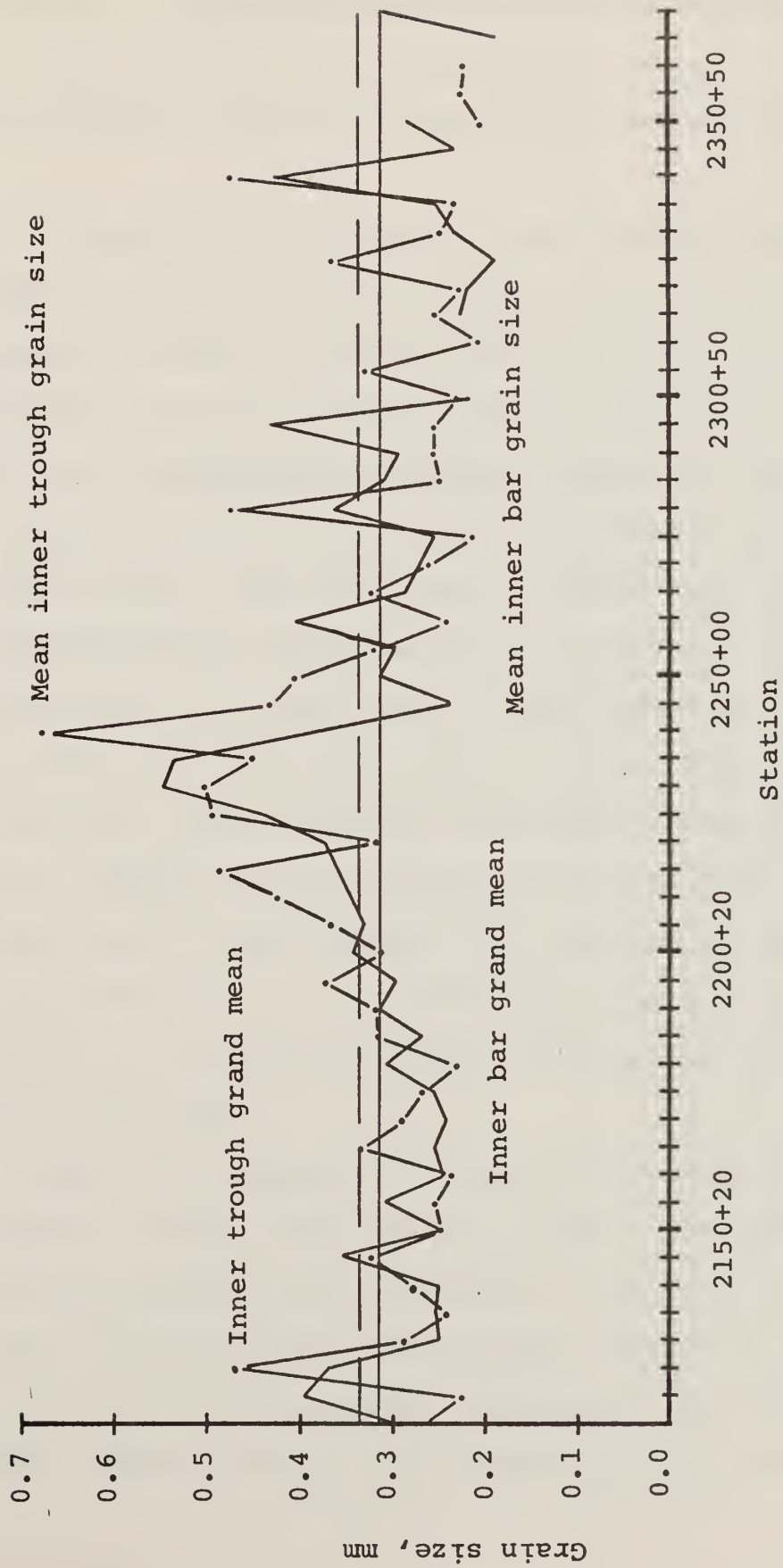


Figure 6.5, Mean inner trough and bar grain size.



was possible. No analysis through time was attempted since only a portion of the entire beach could be surveyed on any one day. The analysis of variance showed a significant difference between stations for both the outer trough and bar.

The majority of the outer trough stations belong to the same homogeneous subset of finer grain sizes, Figure 6.6. A smaller number of stations fall into the coarser subsets. These represent two main zones of coarser outer bar material. One zone is in the northern extreme of the project area. Trough depths in this area have been consistently less than in the other areas. The other zone is around station 2215+50. Trough depths generally decrease from the northern stations to this area and on to the south. Trough depths around station 2215+50 are not unlike those of surrounding stations, so this would not seem to explain the sudden increase in grain size. However, these stations are associated with a gap in the outer bar identified in the previous monitoring project (see Section 3.2). It would seem likely that these two features are in some way linked to an unusual set of processes in this area.

Grain size generally decreases to its lowest value around station 2270+00, south of the groins. The groins do not appear to coincide with any change in the outer trough grain sizes. Deepest trough depths were surveyed in the vicinity of station 2270+00 where samples of fine mud were consistently taken. South of this point, the bar and trough



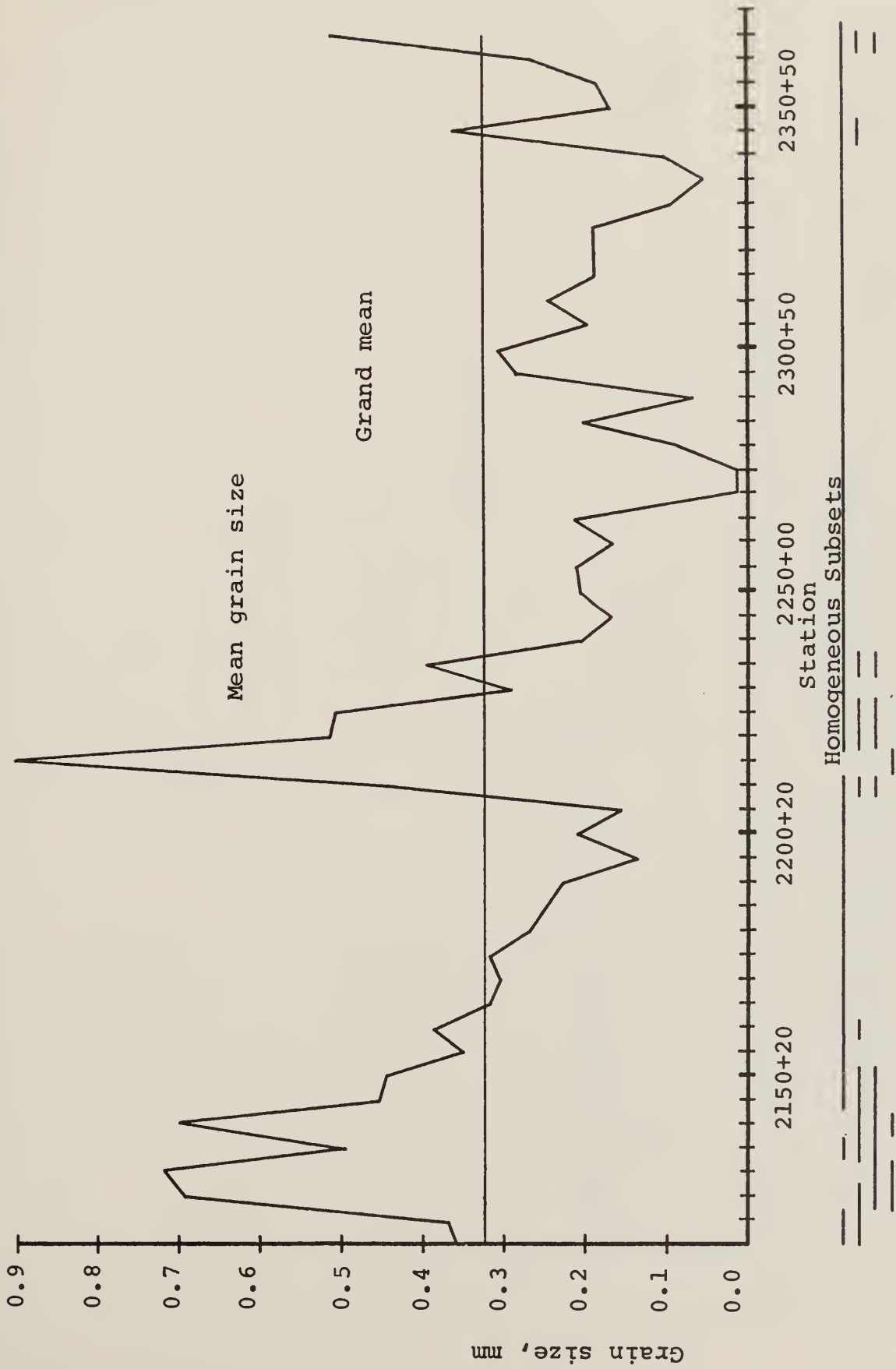


Figure 6.6, Mean outer trough grain size.



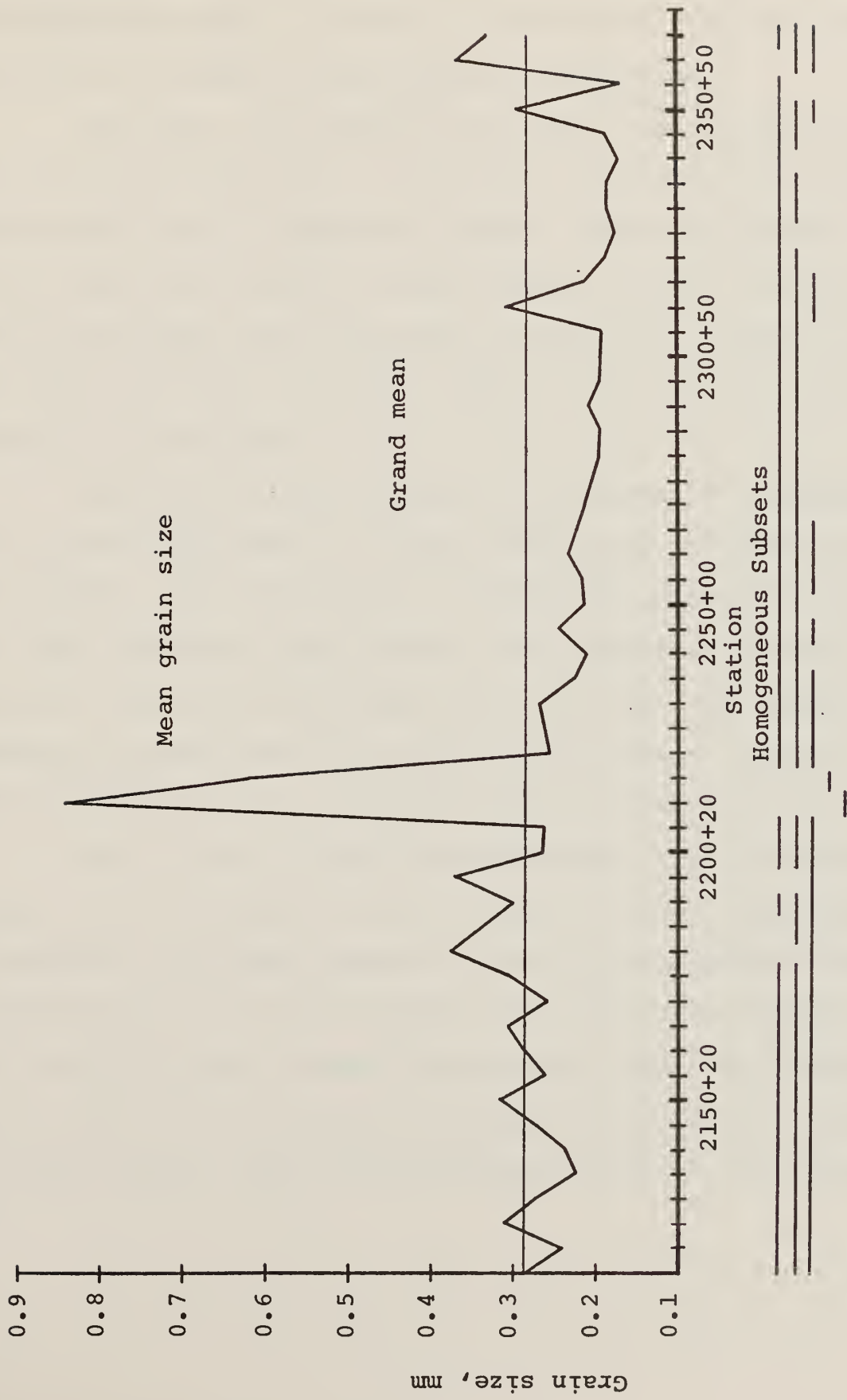


Figure 6.7, Mean outer bar grain size.



morphology degrade into almost nonexistent features. A clear trend cannot be seen in the data. The coarser stations near the Point are a result of the shoals in this zone.

The outer bar sediment data shows less variability than the outer trough data. Once again, the majority of the stations fall into a homogenous subset. There does appear to be a trend for slightly coarser material in the northern half of the project area and again at the Point, Figure 6.7. There does not appear to be any change in mean values in the vicinity of the groins.

The most striking feature of the outer bar sediment data is the large spike of coarser material at stations 2210+50 and 2215+50. Both stations are statistically different from each other and every other station. The anomalously coarser material at this one area support the view that significantly different processes must be acting in this area to result in unique sedimentological and morphological characteristics.

Grain sizes do vary along the beach in all five zones sampled. This variation is not a result of the introduction of anomalous nourishment material since the nourishment sediment has been shown to be almost identical to the native beach sands. The variations along the beach must be the result of different energy inputs or significantly different morphological responses to similar energy inputs along different zones of the project area.



## VII. APPLICATIONS OF REMOTE IMAGERY

Aerial photography has been used extensively to monitor beach changes. Stafford (1971) presents a summary of the problems and methods used in aerial photography monitoring as well as information on various applications of this technique along North Carolina beaches. Most studies with aerial photography have used the photography to compare coastal configuration over time (for example: Athearn and Rone, 1963; El Ashry and Wanless, 1968; Dolan and Vincent, 1973) or to establish rates of erosion or accretion of the shoreline (for example: Stafford, 1973; El Ashry and Wanless, 1965 and 1967). Rates of change are generally determined by measuring the change over time of the distance between some fixed, relocatable point inland of the beach and some feature of the beach such as the dune line, high water line, or water line. An average rate of change, in feet per year, can be determined for a selected area.

With aerial photography, monitoring of beach changes over long sections of beach can be carried out with relatively small expenditures of manpower and money. If this technique could be extended to obtain volumetric changes for selected sections of beach, considerable savings in manpower and cost would also be recognized.

During the planning, pumping, and post-pumping phases of the beach nourishment project, there have been six NASA



aerial photography flights along the project area in cooperation with the Chesapeake Bay Ecological Program, NASA Wallops Flight Center. These were in August 1972, February, June and August 1973, and June and December 1974. When the last four flights were made, the monitoring project of first CRA and then the current project were underway. Each of these flights were within four days or less of a beach survey, so beach volumetric changes between flights could be calculated very closely. This was done, and the results were compared to the area changes from the air photos for the two sample areas, station 2150+20 to station 2195+20 and station 2325+50 to station 2355+50. Average beach thickness above msl was determined from the survey data so that volumetric changes could be derived from the air photos and compared to actual volume changes.

Station 2150+20 to station 2195+20 were chosen as one sample zone because this was the only area that had been completely nourished when the August 1973 flight was flown, Figure 7.1. The second sample zone was chosen near Cape Point, but outside of the influence of the large changes of the Point, Figure 7.2. Results here could be extended to the Point in an attempt to estimate volume changes there.

Each aerial photograph was enlarged to a common scale, approximately 1:5,000. A base map was drawn from one photograph and the others were fitted to the base map. An attempt was made to use only the center portion of each photograph to avoid edge distortion, and when edge distortion became apparent, the photograph was readjusted to more closely fit the base map.



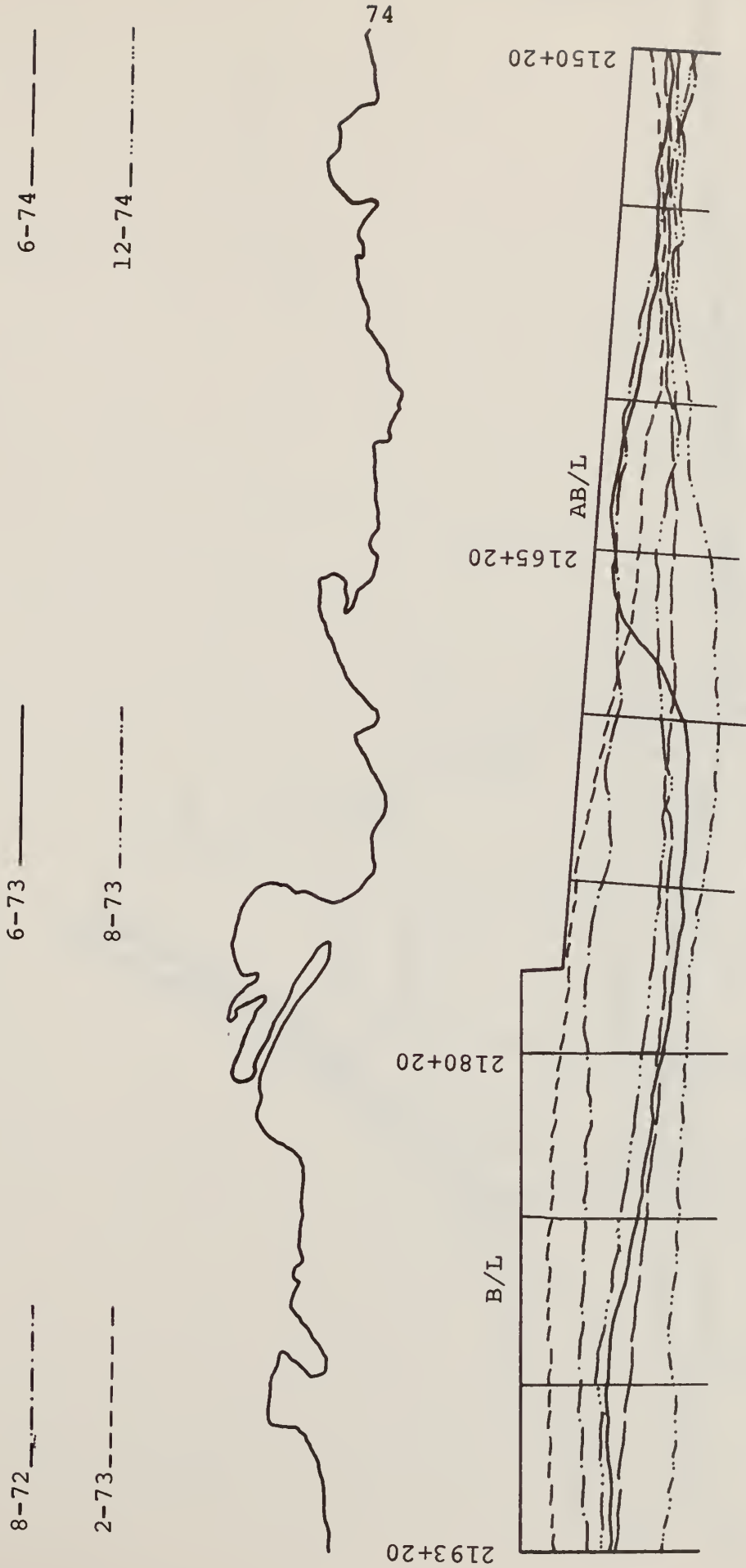


Figure 7.1, Shoreline changes from station 2150+20 to station 2195+20, scale 1:5870



8-72 - - - - -  
 2-73 - - - - -  
 6-73 —————  
 8-73 - - - - -  
 6-74 —————  
 12-74 - - - - -

75

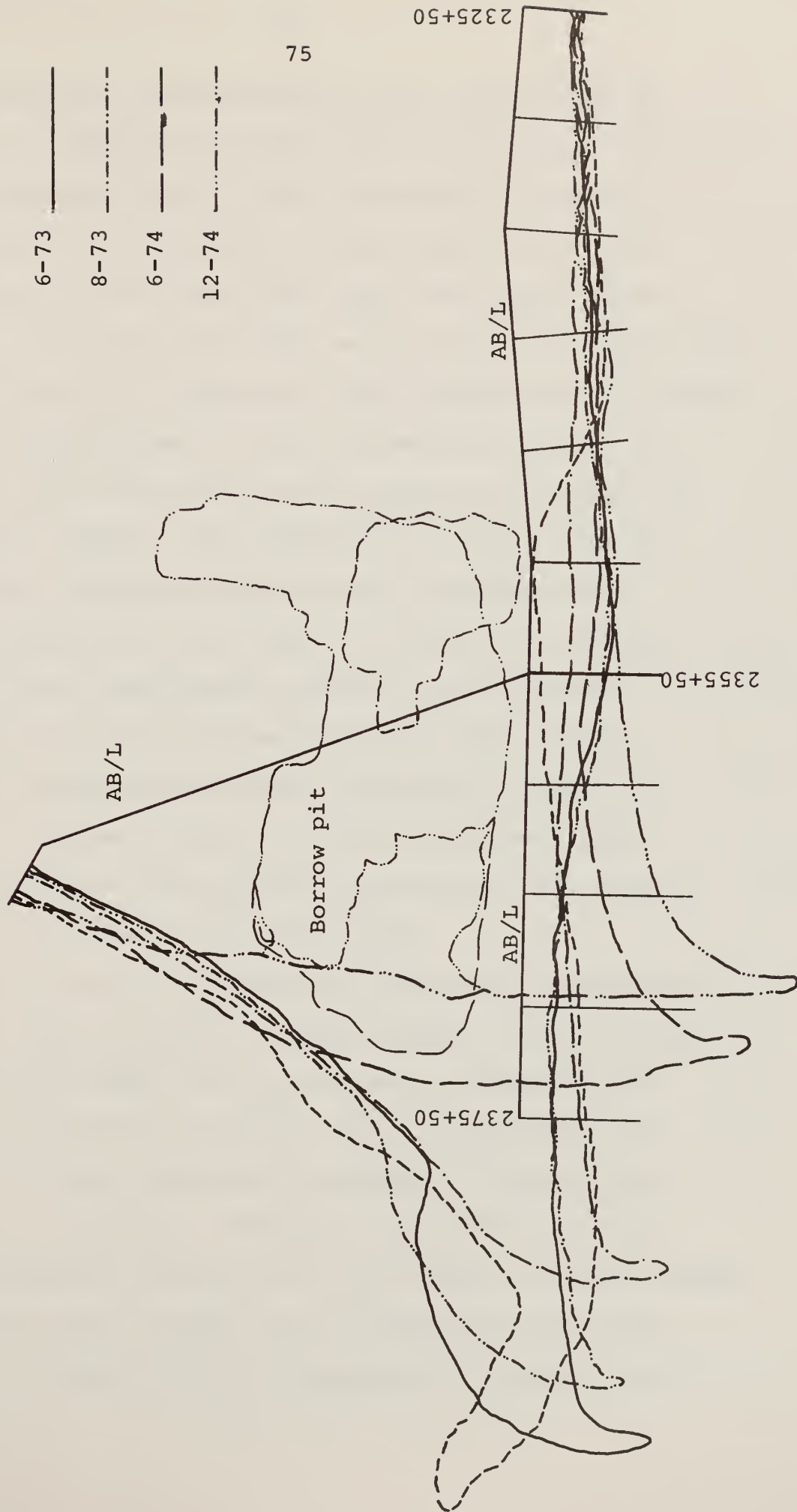


Figure 7.2, Shoreline changes from station 2325+50 to station 2355+50 and at Cape Point, borrow pit retreat, scale 1:8122.



The shoreline traced from the aerial photograph was the water line. Although the high water line has been considered more useful (Stafford, 1973), such a line was not clear on these photographs. In addition, the high water line would exclude a portion of the beach face above msl from volumetric computations. Since the water line was chosen for the shoreline, some later correction for slope and tidal height had to be made.

The six shorelines of each zone were plotted on the same map along with the base lines and stations used for the volumetric beach surveys. The location of these points was determined from a detailed comparison of features on the aerial photographs and in the field. The scale of each map was based on ground measurements between two distinctive points. The area of beach between the base line and the shoreline was then planimetered and the actual ground area was computed. The mean slope of the beach face was taken from the profiles, and the area was corrected for the height of the tide at the time of the photography.

Tables 7.1 and 7.2 compare the volumetric changes from the air photos with the actual volume changes. Percent change (later date/earlier date) for the surveyed sections and the corrected areas from the air photos agree to an average of 6.5 percent. The best agreement was within 0.1 percent and the worst was 9.6 percent. Correcting for tidal height did improve the agreement between actual and remotely sensed changes.

Percent change between the two data sets could have been forced to compare better by enlarging the landward area



TABLE 7.1

## VOLUME DETERMINATIONS FOR STATION 2150+20 TO STATION 2195+20

|                                                 | 8-72    | CHANGE | 2-73   | CHANGE | 6-73    | CHANGE | 8-73    | CHANGE | 6-74    | CHANGE | 12-74   |
|-------------------------------------------------|---------|--------|--------|--------|---------|--------|---------|--------|---------|--------|---------|
| VOLUME FROM<br>PROFILES                         |         |        |        |        |         |        |         |        |         |        |         |
| Volume,<br>cu yd                                |         |        |        |        | 223867  | 134117 | 357984  | -44929 | 313054  | -25542 | 287512  |
| Volume,<br>yd/yd                                |         |        |        |        |         | 89.4   |         | - 30.0 |         | - 17.0 |         |
| Percent<br>change                               |         |        |        |        |         | 159.9  |         | 87.5   |         | 91.8   |         |
| Mean slope,<br>ft/ft                            |         |        |        |        | 0.12    |        | 0.10    |        | 0.11    |        | 0.12    |
| Mean<br>thickness,<br>ft                        |         |        |        |        | 5.83    |        | 6.11    |        | 6.67    |        | 6.73    |
| Tidal<br>height, ft<br>above msl                | 1.8     |        | -1.4   |        | -0.5    |        | -1.1    |        | 1.4     |        | -1.0    |
| AREA FROM<br>AIR PHOTOS                         |         |        |        |        |         |        |         |        |         |        |         |
| Corrected <sup>2</sup><br>area, ft <sup>2</sup> | .720275 |        | 419005 |        | 1070379 |        | 1643120 |        | 1340086 |        | 1118249 |
| Percent<br>change                               |         | 58.2   |        | 255.5  |         | 153.5  |         | 81.6   |         | 83.5   |         |
| Volume, <sup>1</sup><br>cu yd                   |         |        |        |        | 223867  |        | 343680  |        | 280306  |        | 233915  |
| Volume, <sup>2</sup><br>cu yd                   |         |        |        |        | 230964  | 140989 | 371953  | -41104 | 330852  | -51953 | 278899  |
| Volume,<br>yd/yd <sup>3</sup>                   |         |        |        |        |         | 94.0   |         | - 27.4 |         | - 34.7 |         |
| Volume,<br>cu yd                                | 168971  | -57239 | 111731 | 139373 | 251103  | 134360 | 385463  | -71089 | 314374  | -42041 | 262333  |
| Volume,<br>yd/yd                                |         | - 38.2 |        | 92.9   |         | 89.6   |         | - 47.4 |         | - 34.7 |         |
| Volume, <sup>4</sup><br>cu yd                   |         |        |        |        | 245791  |        | 377309  |        | 307723  |        | 256783  |



TABLE 7.2

## VOLUME DETERMINATIONS FOR STATION 2325+50 TO STATION 2355+50

|                                    | 8-72   | CHANGE | 2-73   | CHANGE  | 6-73    | CHANGE | 8-73   | CHANGE | 6-74   | CHANGE | 12-74 |
|------------------------------------|--------|--------|--------|---------|---------|--------|--------|--------|--------|--------|-------|
| VOLUME FROM<br>PROFILES            |        |        |        |         |         |        |        |        |        |        |       |
| Volume,<br>cu yd                   | 226255 | -14187 | 212068 | 36712   | 248780  | -29330 | 219450 |        |        |        |       |
| Volume,<br>yd/yd                   | - 14.2 | 36.7   | - 29.3 |         |         |        |        |        |        |        |       |
| Percent<br>change                  | 93.7   | 117.3  | 88.2   |         |         |        |        |        |        |        |       |
| Mean slope,<br>ft/ft               | 0.12   | 0.12   | 0.11   |         |         |        |        |        |        |        |       |
| Mean<br>thickness,<br>ft           | 6.45   | 6.38   | 6.71   |         |         |        |        |        |        |        |       |
| Tidal<br>height, ft<br>above msl   | 1.8    | -1.4   | -1.1   | 1.4     |         |        |        |        |        |        | 78    |
| AREA FROM<br>AIR PHOTOS            |        |        |        |         |         |        |        |        |        |        |       |
| Corrected<br>area, ft <sup>2</sup> | 851241 | 784862 | 934433 | 1036634 | 1013641 |        |        |        |        |        |       |
| Percent<br>change 1                | 92.2   | 127.2  | 93.6   | 110.9   | 97.8    |        |        |        |        |        |       |
| Volume,<br>cu yd 2                 | 226255 | 211752 | 234165 | 229703  |         |        |        |        |        |        |       |
| Volume,<br>cu yd                   | 238407 | -17708 | 220699 | 47836   | 257661  | -36875 | 220786 |        |        |        |       |
| Volume,<br>yd/yd 3                 | - 17.7 | 47.8   | - 36.9 |         |         |        |        |        |        |        |       |
| Volume,<br>cu yd                   | 200325 | -15621 | 184704 | 50263   | 234968  | 24052  | 243955 | - 5411 | 238544 |        |       |
| Volume,<br>yd/yd 4                 | - 15.6 | 50.3   | - 15.1 | 24.1    | - 5.4   |        |        |        |        |        |       |
| Volume,<br>cu yd                   | 227157 | 212593 | 235845 | 230613  |         |        |        |        |        |        |       |



TABLE 7.3

## VOLUME DETERMINATIONS FOR CAPE POINT

|                                | 8-72    | CHANGE | 2-73    | CHANGE | 6-73    | CHANGE | 8-73    | CHANGE | 6-74    | CHANGE  | 12-74   |
|--------------------------------|---------|--------|---------|--------|---------|--------|---------|--------|---------|---------|---------|
| AREA FROM<br>AIR PHOTOS        | 3556866 |        | 3914077 |        | 3772938 |        | 3702875 |        | 3453654 |         | 3842622 |
| Percent<br>change <sup>2</sup> |         | 110.0  |         | 96.4   |         | 98.1   |         | 93.3   |         | 82.3    |         |
| Volume,<br>cu yd               | 835732  | 83931  | 919663  | -33162 | 886501  | -16463 | 870038  | -58551 | 811481  | -143570 | 667911  |
| Volume,<br>yd/yd               |         | 35.7   |         | - 6.3  |         | - 6.7  |         | - 28.2 |         | - 78.2  |         |

NOTES TO TABLES 7.1, 7.2, and 7.2:

1. Volume - Surveyed volume on 6/73 x Percent change
2. Volume - Corrected area x Mean thickness/27
3. Volume - Corrected area x Grand mean thickness/27
4. Volume - Corrected area x Mean conversion factor

$$\text{Conversion factor} = \frac{\text{Surveyed volume}}{\text{Corrected area}}$$



considered. This would have made beach face changes relatively smaller but would make the results less meaningful. The aerial photography appears to give a good estimate of the percent change within the boundaries of the project area.

Absolute volume changes from the aerial photography can be computed by several methods. Tables 7.1 and 7.2 give volumes computed four ways as well as the change and change per yard between photo dates. The June 1973 surveyed volume was used as a base volume and was multiplied by the percent change to give volumes on the other dates. The average thickness of the beach for each area on each date was computed from the survey data and multiplied by the corrected area. The mean thickness for all four dates was used instead of the thickness of each date. Finally, the surveyed volume was divided by the aerial photograph's area to obtain a correction factor for each data and the mean correction factor for the four dates was used to recompute volume.

Each method gives reasonable estimates of the total volume on the beach. As would be expected, the volume computed from the thickness on the date of the flight gives the best estimate. However, no method gives a consistently good estimate of volume change. Total volume of material on the beach above mean sea level as computed from the aerial photography varies from the actual volume by 19 percent at worst. However, changes between two dates are underestimated by a factor of 6 in one case. It would appear that the total volume can be obtained from the aerial photographs almost as well as the



percent change, but the change between two dates cannot be obtained with any confidence.

Aerial photography appears to be of little use for documenting the small scale changes. In spite of this failure, the agreement in total volumes and percent change is reasonably close, probably close enough for a less detailed monitoring of a nourishment project or for a general monitoring of changes along certain selected areas of beach. Only a moderate amount of ground truth data is needed.

The analysis of percent changes was expanded to include the two dates before the establishment of the monitoring projects and to include the Point and south side of the Point where no monitoring was carried out, Tables 7.1, 7.2, and 7.3. The impact of the February 1973 storm on the beach is clearly seen in the large drop in material in the northern zone, but the percent change in the southern area was much smaller. The relative magnitudes of these figures appear to agree well with the field observations during the storm.

The recovery of the beach after a major storm as well as the impact of nourishment is also well illustrated in the percent change between February and June, 1973. Accretion in the southern zone was largest during this period but was small when compared with the combination of natural and pumped accretion to the north.

Figures for Cape Point indicate an almost steady loss of material during this time period. Accretion at the Point only took place between August 1972 and February 1973.



## VIII. ANALYSIS OF SHORELINE VULNERABILITY

A method of predicting areas of barrier island storm vulnerability, e.g. overwash and erosion, would be of value in the management of this seashore. This section deals with the initial stages in the development of such a method and reports on the progress of the work to date.

In assessing the vulnerability of the barrier island chain, vulnerability will be defined as the propensity towards destruction or disruption of the permanent, man-made structures by the action of the sea. The effects of storms on the buildings, roads, barrier dunes, and power and telephone lines are the primary concern.

Examination of aerial photography and field studies suggests that there are well-defined problem areas at which either erosion or overwash creates a distinct threat to the continuity of the island. The extent of these areas (from 0.25 to 2 miles wide) points toward localized causes. This rules out storm surge as a primary cause, as well as tidal range, because of the broad areas which these generally effect. Waves are the most likely cause of these localized problems since they are responsible for the erosion. To be more correct, it is the differential wave heights along the coast which determine the wave power and thus the spatial distribution of high rates of sediment movement.



Differential wave heights are a result of the superposition of waves as they travel to shore, raising the elevation of the wave crest. This occurs by either overtaking waves or by the refraction of waves and the concentration of energy into a smaller surface area as the waves converge upon themselves. The present analysis is concerned with the refraction of storm waves and their effects on the shoreline.

A number of studies of this nature have been done in the area, Langfelder (1970), Corps of Engineers (1969), using the fair weather wave climate. However, since storm waves are generally the cause of large scale erosion and overwash, the existing studies are not reliable for determining problem areas, Langfelder (1970). To improve this situation, the present study uses waves hindcast by the Bretschneider revised, Sverdrup-Munk method, for specific storms known to have caused erosion or overwash. This will give a more realistic model of the situation during a storm.

The wave refraction will be simulated using an analytical model developed at the Virginia Institute of Marine Sciences (VIMS), in a joint Sea Grant Project with NASA Langley Research Center, Goldsmith, et al. (1975).

In order to implement this model, it was first necessary to produce a detailed bathymetric map of the continental shelf near Cape Hatteras to a depth of 150 feet. This was accomplished through the use of U. S. Coast and Geodetic Survey's hydrographic sounding sheets. A grid of 59,340 individual depths was produced with even spacing of 0.25 nm



to encompass the entire area surrounding Hatteras Island and Bodie Island.

The most recent available hydrgraphic sounding sheets were obtained for the Cape Hatteras area and overlain with a reference grid of the correct scale to provide 0.25 nm intervals. The individual depths were then transferred by hand onto a master grid corresponding to a large map of Cape Hatteras National Seashore. Once the master grid was completed, the values were then tabulated in order to form a data base from which computer cards would be punched.

This grid was then entered into the computer in data card form, creating a 345 by 172 data matrix. From this, profiles of the continental shelf off Cape Hatteras were plotted to ensure that there were no anomalous depths in the grid. With these data, the wave refraction model can be run for selective wave conditions. Thus, the exact wave conditions of a specified storm can be run in the proper order to simulate the effects of a particular sequence of events leading to erosion. As shown in Section IV, equal wave heights do not necessarily contribute equal amounts of erosion or vulnerability. It is the sequence, directions, and periods of wave attack which determine how extensive the erosion will be.

As a test of the method, the extensive data collected during the project will be used to isolate storms and their erosive results as has been summarized in Section IV. The same wave parameters will be input to the wave refraction



model and shoreline energy histograms calculated along the length of beach for which there are data. The shoreline energies will then be correlated with the actual survey results to determine the model's reliability.

The groundwork has been laid and most of the labor, such as recording the almost 60,000 depths and the refinement of the grid, has been accomplished. A run was completed for a section of deep water off Rodanthe to ascertain if the model was sensitive to the depth grid; with good results, Figure 8.1.

Some early results were obtained from the VIMS-NASA Langley wave model, Goldsmith, et al. (1975), using a wide range wave climate for the east coast. Figures 8.2 and 8.3 are examples of the wave diagrams. Areas of convergence of wave rays and thus of high energy densities were obtained from a composite of 35 different combinations of wave period and direction. Areas of accelerated erosion and of chronic overwash were defined using field studies and NASA aerial photography from 1965. The results were then superimposed on a map of Hatteras island as shown in Figure 8.4. This figure suggests a correlation between erosion/overwash areas and this composite wave climate. It is anticipated that this approach will yield improved results when the wave conditions for individual storms are correlated with the resulting shoreline change for that storm.



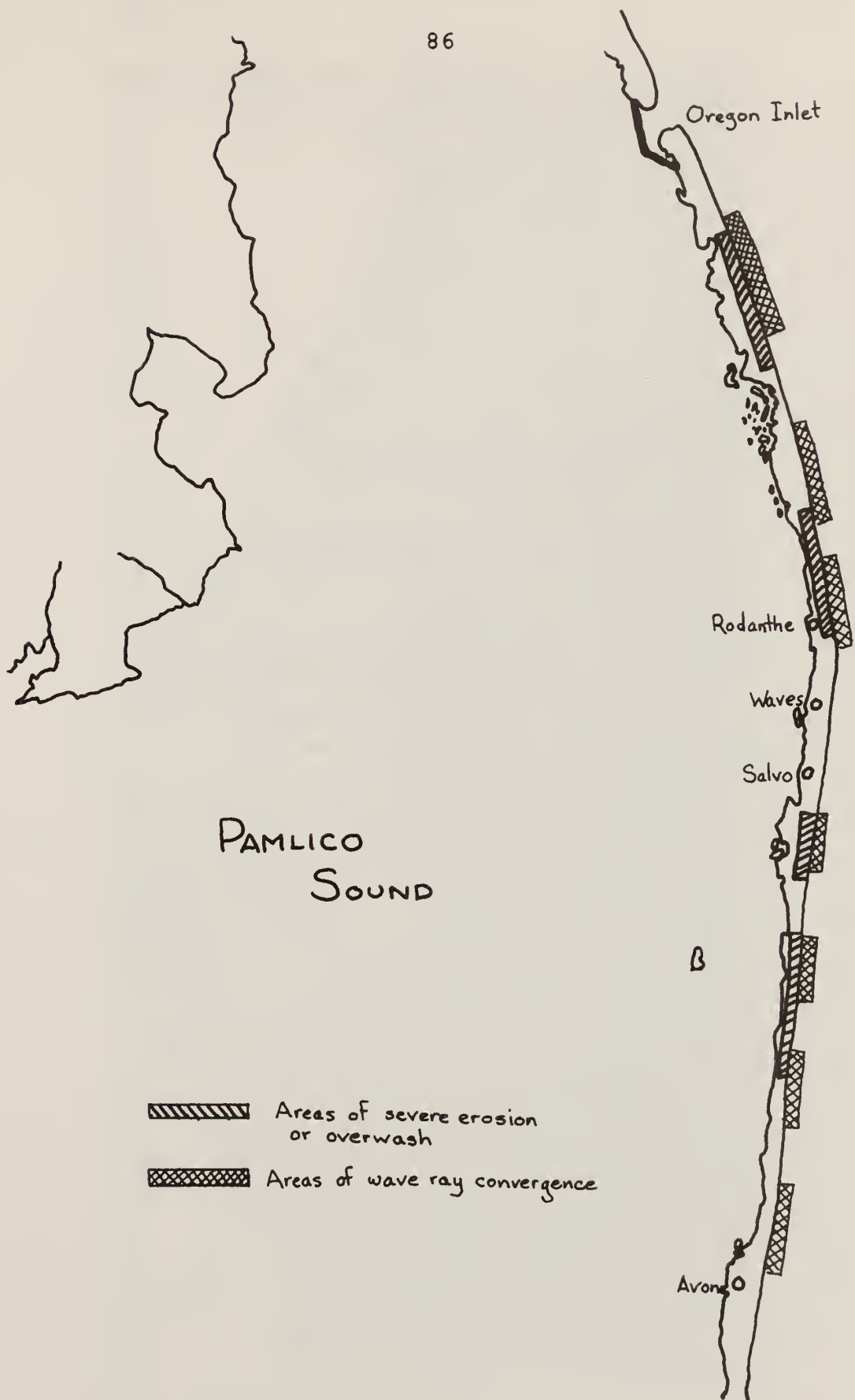


Figure 8.1, Correlation of areas of accelerated erosion or overwash with areas of wave ray convergence.



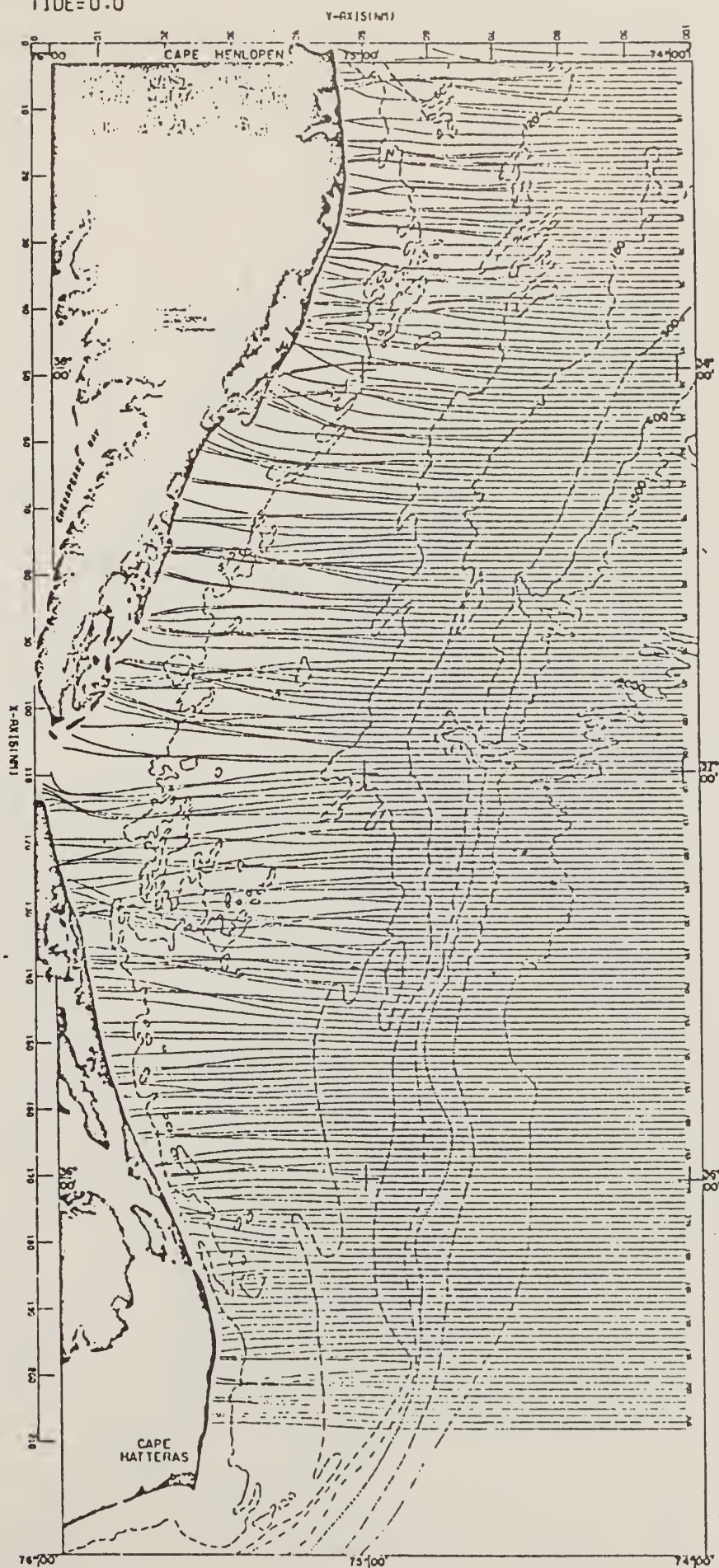


Figure 8.2, Preliminary wave refraction study  
(from Goldsmith, et al., 1975)



TIDE = 0.0

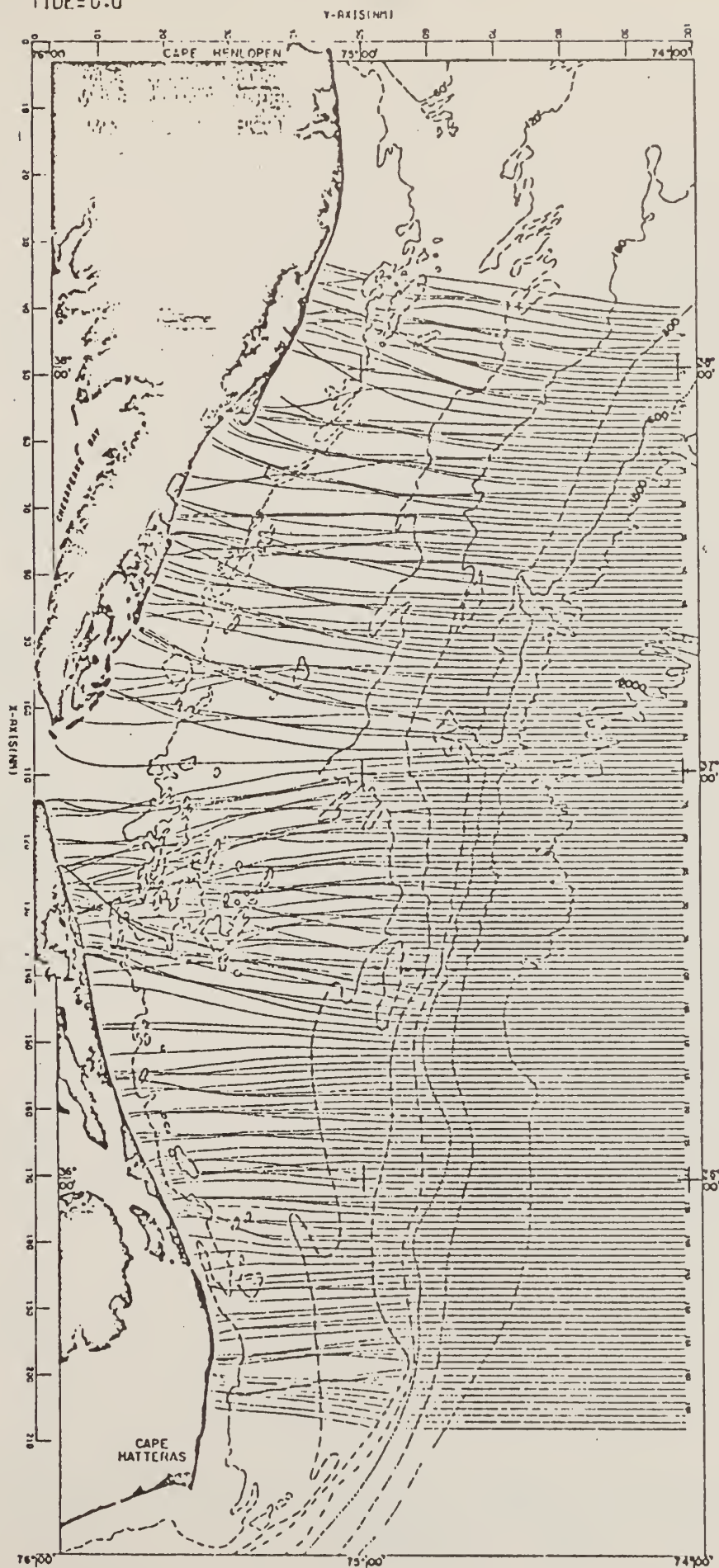
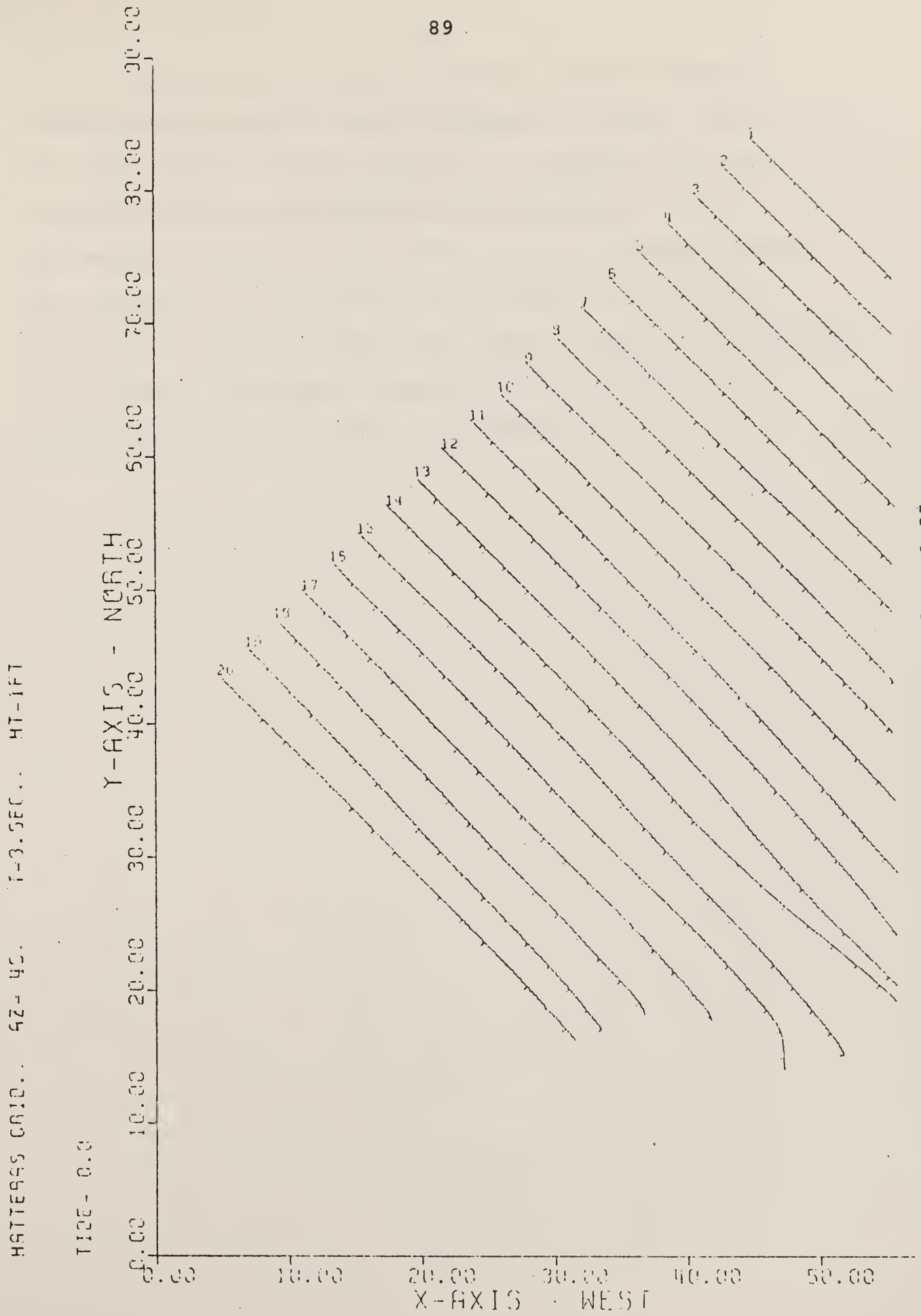


Figure 8.3, Preliminary wave refraction study  
(from Goldsmith, et al., 1975)







A model of this type would be of great value in shoreline and barrier island management programs. Storms of any type could be either forecast or hindcast as to their expected effects, and remedial or preventative measures could be taken in accordance with the results. A moderate amount of refinement and calibration work remains to be done to perfect the method, however, the labor of setting up the model is finished. Preliminary results and the outlook for a complete and reliable model are promising.



## IX. SUMMARY AND CONCLUSIONS

This project has made a comprehensive study of the movement, changes and impact of the 1972 Cape Hatteras beach nourishment during its first post-pumping year. In addition to the monitoring of the fill itself, the storms, waves and other physical factors, as well as the ecological impact of the fill have been studied. An evaluation of remote imagery as a tool for continued fill monitoring has been made, and an initial appraisal of a wave refraction model for the prediction of severe erosion areas is presented.

In general, this post-pumping period has shown the nourishment project to have been an initial success. Approximately 50% of the fill material has remained either on the subaerial beach, or in the nearshore zone. This material has sustained a wide beach for recreation as well as some measure of storm protection to the property landward of the beach. A major factor in this relatively high level of retention has been the mild extra-tropical storm season, with about one third fewer significant storms than average. The future pattern of retention cannot be assumed to continue at these same high levels.

The anticipated filling of the borrow pit from overwash on the north side has been very small. In fact, the only



significant change has been the inlet and erosion on the south side and the turning and migration to the north. Much of this latter change is the result of the erosion and southward transport of the fill material.

No ecological impact of the fill can be seen, as determined from the distribution of Emerita talpoida in the swash zone. Earlier studies suggest the validity of this organism as an environmental indicator, and so the net ecological impact can be assumed small or zero. This conclusion is consistent with the earlier studies of Coastal Research Associates.

The sediment distribution along the project area indicates that no stratification of the pumped material has occurred beyond the natural equilibrium generally found at Cape Hatteras. This conclusion was anticipated inasmuch as the fill material was practically equivalent to the natural beach sand.

The application of aerial photography to the post-pumping study of a beach nourishment fill proved to be a partial success. Although detailed changes can only be computed from ground surveys, gross volume estimates and changes can be measured from the imagery with a limited amount of ground measurements. This result suggests that a program of continued aerial photography and limited ground surveying should be implemented.

The initial results from the wave refraction model suggest that this tool is of potential use in the development of shoreline use plans. Further study and evaluation is needed in order to refine this model.



The large quantity of data collected during this past year will require considerable more time to study. These future analyses should provide many new insights into the complex processes of coastal dynamics. This report has presented only gross analysis of this data, and the basic skeleton of these future studies.



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